ENGINOLOGY

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BEFORE there could be powered flight, there had to be power — power of a special sort. The Wright brothers, at the very start, discovered how special were these requirements for an aircraft power plant. They had to spurn the steam engine as too heavy, the electric motor as dependent upon an earthbound generating station. They had to reject as too ponderous whatever the market of their day offered in internal combustion engines. Internal combustion engines being the obvious solution, however, they looked for one which would give them what they needed — and finally had to build their own.

That power plant for the first successful man-carrying machine was primitive, heavy, and undependable by present-day standards. But it was nevertheless adequate for powered flight — adequate because it filled the special needs by possessing special characteristics.

SINCE then, the nature of a power plant for aircraft has diverged even more sharply from that of an engine used, for example, for an automobile or a marine power plant. The auto engine continues to get along very well weighing in the neighborhood of ten pounds per horsepower, just about the same weight per unit of power as that recorded for auto engines when the Wright brothers were getting started. The non-flying breed of engine, further, continues to get along quite comfortably without a supercharger, without such things as dynamic dampers, without elaborate self-compensating controls built into carburetors.

The aircraft engine, a specialist in its field increasingly as the years have passed, has become increasingly thrifty in weight-per-horsepower, increasingly powerful, ever more conserving of fuel, more and more versatile in the altitudes and weather conditions at which it will continue to function, and more and more rugged — rugged to the point at which it can carry its aircraft across whole hemispheres without pausing for rest.

AS a direct descendant of the Wright brothers' first aviation enterprise, the Wright Aeronautical Corporation considers that it belongs to one of the "first families" of powered flight — not only because of its genealogy, but because the engines which it manufactures have carried these special characteristics of the ideal aircraft engine to the most advanced point attained anywhere. These

engines are Cyclones and Whirlwinds. The Cyclones are the "draft horse" power plants, the models ranging from the neighborhood of 1,000 horsepower to 2,200 horsepower. The Whirlwinds, junior members of the Wright engine family — though senior in the fact that they were developed before the first Cyclone — include models possessing output up to 400 horsepower.

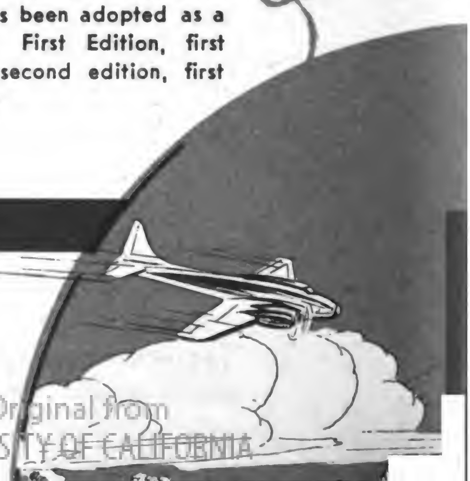
Just as the aircraft engine per se is a special type of power plant, so the radial engine such as a Cyclone or Whirlwind, is a special type of aircraft engine.

NOW, after 25 years of building the radial type aircraft engine, the Wright Aeronautical Corporation looks forward to a post-war period in which, while continuing in the radial field, it will also take its place as a leading manufacturer in the new field of gas turbines and jet propulsion. As this edition of Enginology goes to press, at the start of 1945, Wright technicians have announced that a 10,000 horsepower gas turbine is a possibility within the next ten years. Because the mechanics of the gas turbine and the jet propulsion power plant are radically different from those of the internal combustion engine — because they are a story in themselves — no attempt is made to describe them in this booklet. Some future edition of Enginology for future aircraft engine students will surely open the doors to this new field.

Meanwhile, the reader is advised to remember that more than a generation of experimenting and testing has been spent on the internal combustion aircraft engine of the "reciprocating" type. The best engineering brains in a nation of best engineering have brought this power plant to the point at which it weighs less than one pound per horsepower, can operate at any altitude and in any weather, and can fly giant loads across whole hemispheres.

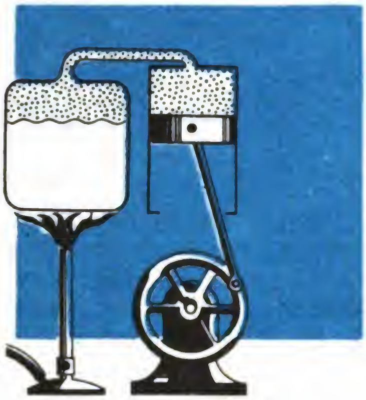
The gas turbine and jet propulsion are definitely just beyond the horizon. But the internal combustion engine with which this book deals will continue as the most useful and the most economical in its field for a long time to come.

This is the SECOND EDITION of ENGINOLOGY, revised and enlarged since the FIRST EDITION. Published originally for the guidance of new employees of Wright Aeronautical — as an introduction to internal combustion engines — the book has been requested by thousands of persons outside of Wright Aeronautical; students, aviation mechanics, airlines and manufacturing personnel, instructors and teachers. It has been adopted as a supplementary text in hundreds of aviation classes. First Edition, first printing, in May, 1944; second printing, June, 1944; second edition, first printing, November 1944.



No. 1 — What Is an Internal Combustion Engine?

With very few exceptions, today's aircraft are propelled by internal combustion engines. Planes first flew 40 years ago this year because of this type of power plant; first flew after generations of men had tried but failed to make them fly by handpower, footpower, steampower—even electrical power. As the name implies, the internal combustion engine is a power plant in which combustion of fuel takes place within a restricted area; in the case of the Cyclone 14, for example, the combustion of fuel occurs within each of the 14 cylinders.



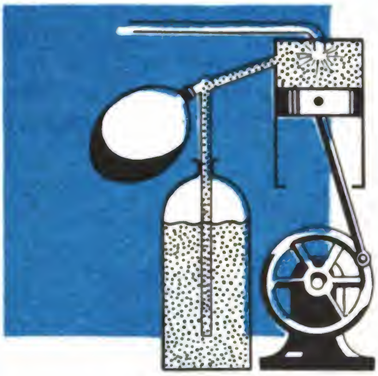
It helps to picture an internal combustion engine by contrasting it with such types of power plants as the steam engine. The steam engine is sometimes given as an example of the external combustion engine; while the expansion of steam also occurs within a cylinder, the steam is generated at an external source, called a boiler, where the fuel heats the water to make steam under pressure.

The drawing here shows a diagrammatic set-up of a steam engine: burning of the fuel to produce heat, notice, takes place outside the chamber where the expanding gas (water vapor or steam) accumulates.

In internal combustion engines —whether the fuel is kerosene, alcohol, fuel oil, or gasoline, (as for Wright engines), the combustion occurs within the chamber from which the driving force moves the piston. In this diagrammatic set-up of an internal combustion engine, an atomizer at the top supplies vaporized gas mixed with air; an electrically-produced spark below supplies ignition. Result: combustion — rapid expansion — power. Technically, remember it's combustion or burning that takes place — but so rapidly that the event within a cylinder is often called explosion.

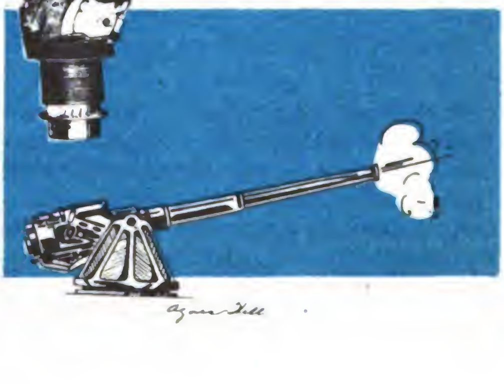
One such explosion may be an experiment — or an accident. Many thousands occurring in swift progression within one or more cylinders is what happens in an internal combustion engine.

While later chapters of ENGINOLOGY will show how these combustions are made to occur rapidly and precisely, here are a few of the necessary components of an in-

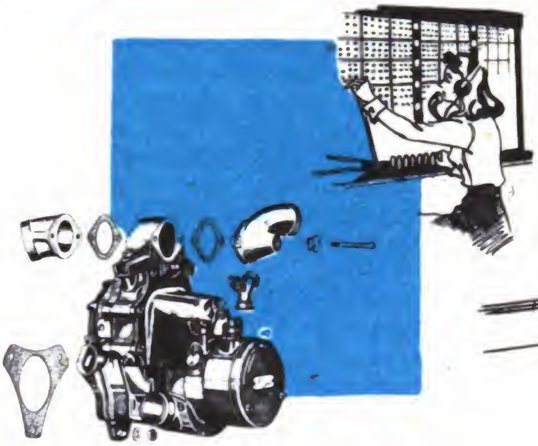


ternal combustion engine like Cyclones and Whirlwinds:

The **cylinder** may be compared to a cannon barrel. In it the explosions occur — but they push pistons instead of cannon balls.

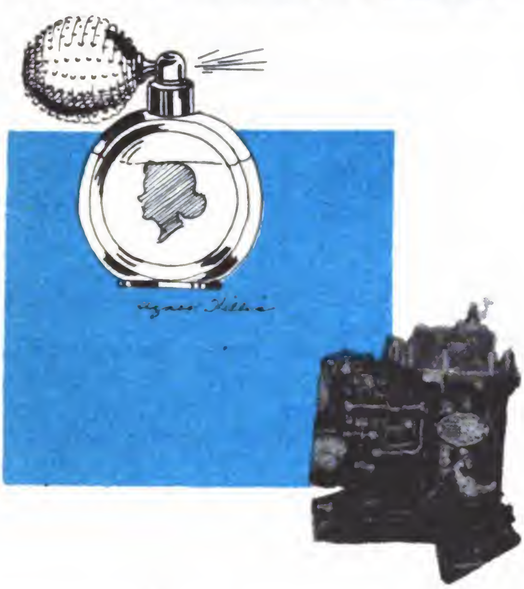


Like a telephone switchboard in many ways is the engine's **magneto.** Its ignition-distributing function makes connections to



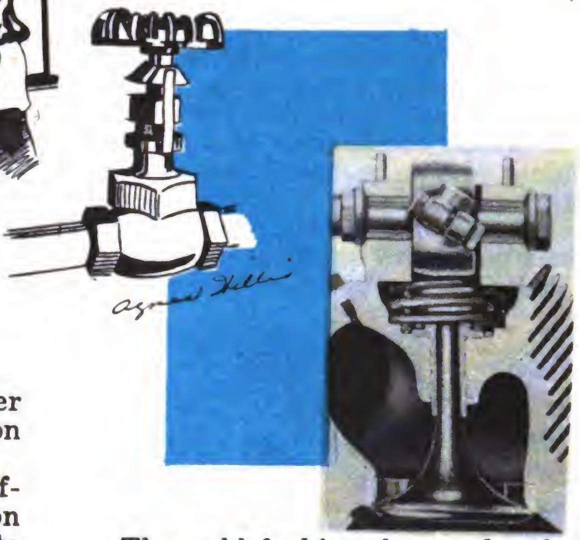
the spark plugs in each cylinder so that each receives the ignition spark at the proper time.

A lot like an atomizer in effect — though not in construction —is the engine's **carburetor.** Its job is to introduce the fuel into the induction passage and from there to the combustion chambers,

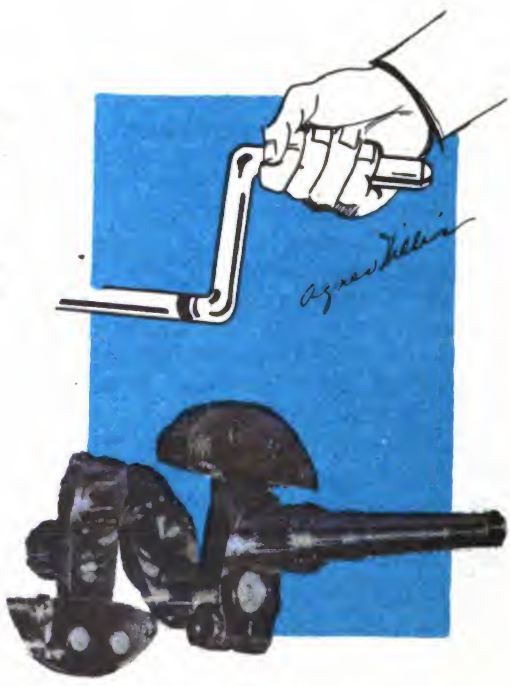


controlling its flow from fuel tanks, breaking the liquid gasoline up into vapor form and mixing it with air so that the resulting combination will burn under compression so rapidly and forcefully that mechanized energy or power is produced.

Valves in an engine are like valves in a water main; closed, they keep gas-air mixture in the cylinder where combustion takes place. Exhaust valve, open when intake valve is closed, permits burned gases to escape and makes room for the next entrance of gas-air mixture by way of the intake valve.



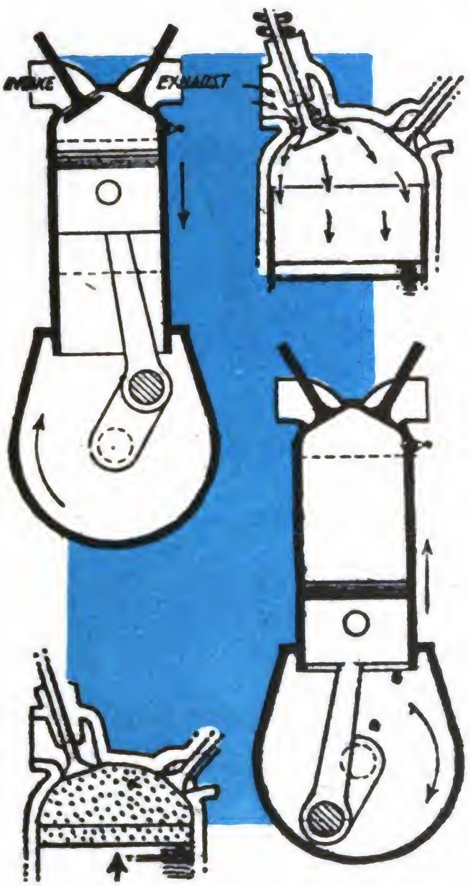
The old-fashioned crank that wound up the well rope, the crank that started the first horseless buggies — these have up-to-the-minute counterparts in the engine's **crankshaft.** The principle is the same, for cranking up the old oaken bucket, or spinning the prop of a Clipper: the crankshaft's job is to translate straight-line motion into rotary motion.



No. 2 — The Four-Stroke Cycle

Most types of internal combustion engines make use of the four-stroke cycle principle. One who knows the principle of operation of the conventional auto engine knows the fundamental facts about the four-stroke cycle as it is employed in an aircraft engine.

To understand the four-stroke principle, it is helpful to realize first what must occur within the cylinders of an engine in order to produce power. The occurrences within any cylinder are these:



A—Top Sketches: B—Bottom

First, the mixture of gasoline and air must be brought into the cylinder.

Second, for efficient combustion that mixture must be compressed in as small a space as possible so that maximum pressure can be derived from the rapid combustion. To see why compressing the gas-air combination produces greater pressure, think of the combustible mixture as it might appear through an exceedingly high-powered microscope.

It would look like millions of hailstones (the molecules of air and fuel) floating about in space. Widely separated, in the small space above the piston, these millions of particles would constitute a smaller total supply of energy-producing material than many more particles in the same space. Compression, therefore, is somewhat akin to heaping more coal on the fire in a steam engine.

Third, for power, the ignition spark in each cylinder must ignite the mixture, causing it to burn. Heat is liberated by combustion and the pressure above the piston rises tremendously because the gas is heated by its own burning. Power is created when the hot gas expands and pushes the piston ahead of it.

Fourth, to complete the cycle, the burned gases of combustion must be eliminated from each cylinder to make it ready for the next cycle.

Those are the four steps of work in the four-stroke cycle engine. In terms of strokes, this is what happens. The letters refer to the illustrations:

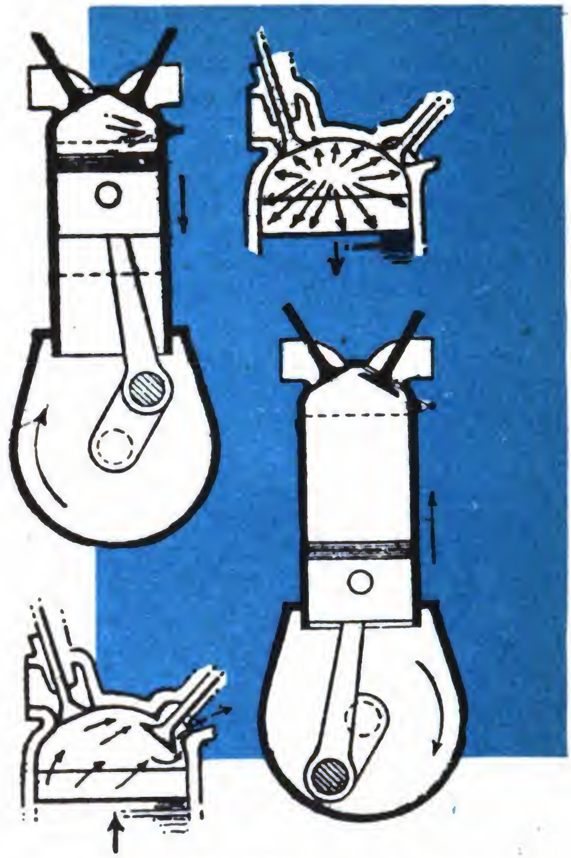
A—The **intake** stroke. Piston moves downward as intake valve (upper left) is open to admit gas-air mixture. As it moves away from the top of the cylinder, piston leaves behind it a partial vacuum which pressure through fuel-induction system immediately fills with the combustible mixture.

B—The **compression** stroke. After reaching the bottom of its stroke, piston begins to move upward, with both exhaust and intake valves closed to prevent escape of the gas-air mixture. Because the mixture cannot escape, it is compressed into narrow space at the

top of the cylinder (combustion chamber) by the time the piston gets to the top.

C—The **power** stroke. With both valves still closed, electrical spark from spark plug ignites the gas-air mixture, rapid combustion followed by expansion forces the piston downward (toward crankshaft). Piston moves connecting rod; rod, like an arm turning a crank, turns crankshaft.

D—The **exhaust** stroke. Exhaust valve (upper right) opens to permit burned gases to escape. Intake valve remains closed to keep burned gases from backing into fuel induction system. Rising piston, like a pump, pushes the exhaust gases out through the exhaust valve, leaving cylinder cleared for the next cycle.



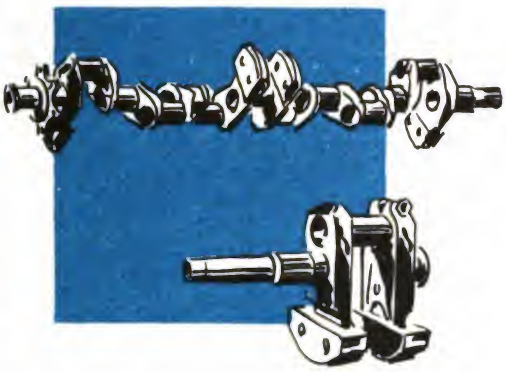
C—Top Sketches; D—Bottom

Equal in power to a fair sized freight locomotive, a 2,200 horsepower Cyclone weighs no more than the locomotive's wheels alone, takes up less space than there is in the cab.

No. 3 — Types of Engines

This internal combustion engine family of which Cyclones and Whirlwinds are members is a big one. It is big because these power plants can be built in many different sizes, from one-cylinder types that drive washing machines to 18-cylinder types that propel giant air transports.

It is a big family, too, because these engines can be built in many different forms — as many different forms as it is possible to find



Above, V-engine crankshaft; below, Cyclone crankshaft

efficient arrangements of one or more cylinders.

In practically every type of internal combustion power plant the cylinder or cylinders are arranged around one or more crankshafts so that the latter serves as collector of the engine's net power, translating the upward and downward strokes of the pistons and their connecting rods into rotary motion.

Operated One Crankshaft

In arrangement, the internal combustion engine in its earliest stages first appeared as but one or two cylinders operating one

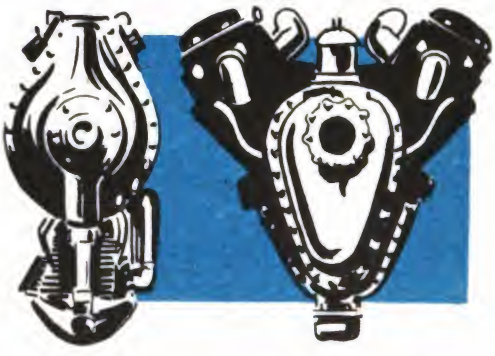
Horizontal opposed

crankshaft. As more was learned about the engine it became possible to produce power plants with rows of cylinders in a straight line, rows of cylinders in parallel lines, and rows of cylinders in lines which formed angles to one another.

These types of internal combustion engines today include the "V," "X," "H," "W" and "in-line." As the letter indicates, the "V" type engine has two or more cylinders arranged at angles to one another in such a manner that the crankshaft is at the point of the "V" and two cylinders, or two rows of cylinders, stem from the crankshaft forming a "V" silhouette in their relation to one another.

Forms X Pattern

In the same manner an "X" type engine has its cylinders arranged to form an "X" pattern,



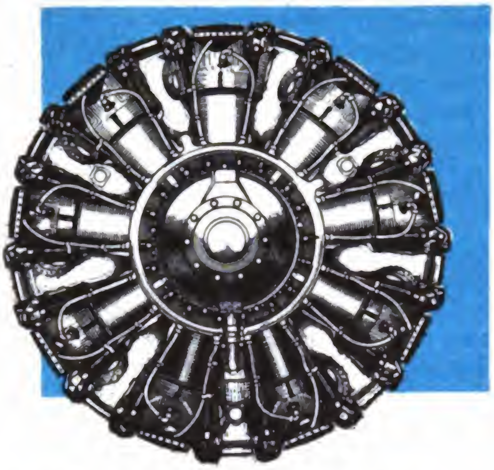
In-line air cooled; (r) "V"

with the crankshaft at the intersection of the two crossing lines of the "X."

The radial type engine, which arranges its cylinders at intervals around a circle, entered the power plant scene on a practicable basis comparatively late. True, in 1903, a young engineer named Charles Manly made the first of the radials — one in miniature as an air-cooled type; the other in full size, as a water-cooled model.

But the design did not come into general use until Charles Lawrance, profiting from experi-

ence on all other types of internal combustion engines, made successful power plants on the radial pattern. Lawrance's en-



Radial air-cooled (Cyclone)

gines were the true predecessors of Whirlwinds; Whirlwinds in turn provided the experience that went into Cyclones.

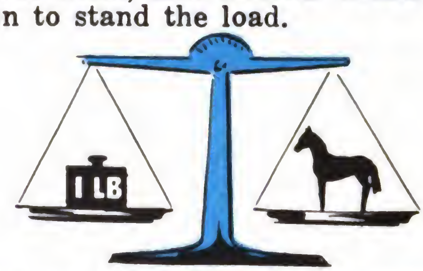
Has Its Advantages

The radial air-cooled engine as it stands today has certain advantages over other types of internal combustion power plants. These advantages are characteristic of the design. For one thing, the radial is inherently lighter in weight. A recent model of a Cyclone engine became the first internal combustion engine in history to produce one horsepower for each pound of its weight.

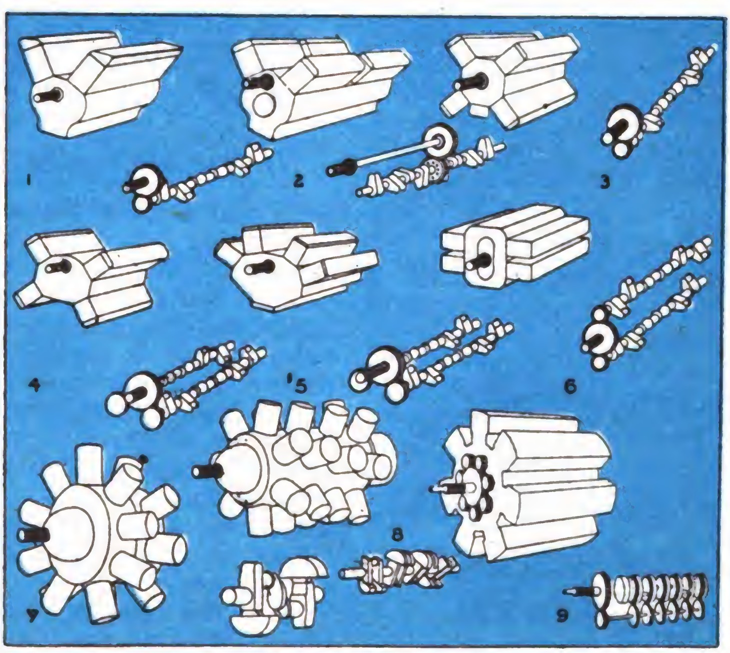
Lightness in the radial air-cooled type comes from many things. Among them are such features as these:

Cooling system — This type of engine is cooled by the air stream rushing through finely spaced fins on cylinder heads and barrels. The weight of the cooling liquid and the system itself is avoided.

Simplicity of construction — Crankshafts, for example, take the power from many cylinders on one bearing surface. In-line engines require separate crankshaft sections for each cylinder, separate bearings between cylinders to brace them, and heavier construction to stand the load.



Cyclone first to achieve pound-per-horsepower



Geometric layouts of reciprocating engines.—(1) V12 (2) V16 (3) X 24 (4) twin crankshaft (5) W 24 twin crankshaft (6) H 24 twin crankshaft (7) two-row radial (8) four-row radial (9) six-row radial

From "The Aeroplane" Magazine.

No. 4 — Engine Requirements

An aircraft engine is not merely a gasoline engine so constructed that it can be bolted upon the framework of an airplane and made to turn a propeller. Actually, the aircraft engine is as specific a type of power plant as the marine engine that drives a boat or the steam engine that drives a locomotive. It would not be practicable to mount the high horsepower Cyclone in an automobile — any more than one could profitably reverse this course and expect auto engines to fly a DC-3.

Taking off—as this Cyclone powered DC-3 is doing on war mission —requires reserve of power, available at touch of throttle.

As a preliminary to considering some of the more detailed information about such engines as Cyclones and Whirlwinds, it may be useful to start with the foundation for that information in the form of a collection of facts on what the engine must **do** and what the engine must **be**. These "musts" influence every step of the long process of engine design, and have a direct bearing upon all of the intricate care and precision used in manufacturing and inspection.

The engine must be light in weight. In the Cyclone and Whirlwind family, engine weights range from one pound per horsepower to a shade less than two pounds per horsepower. Compare this to approximately ten pounds per horsepower for the average auto engine and 15 pounds per horsepower for one of the latest "light weight" Diesel engines for a modern streamlined train.

The engine must be rugged. An auto engine under normal conditions is operated at one-third or less of its total potential power and makes journeys usually of less than 100 miles at a time. An aircraft engine must operate at well over 50 percent of total power to maintain the aircraft's flying speed. It must be durable enough to operate continuously for a 150-hour

"type test" to be accepted for military use; 50 hours of this time is operated at "rated power" and ten hours is at the high power required for takeoff. Note further that it is common for aircraft engines today to make non-stop journeys of a thousand miles or more.

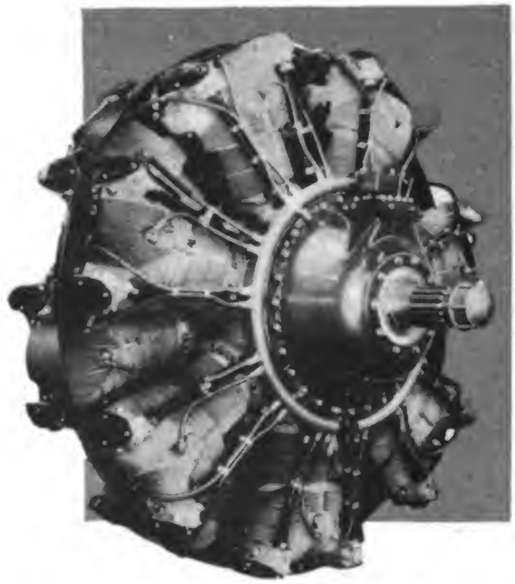
The engine must operate at all altitudes. The Cyclone in a B29 or a Flying Fortress, for example, must be able to take off at sea level and climb immediately to altitudes five miles or more above the earth.

An engine must adjust itself to wide temperature differences. The Cyclone in the Douglas Boston, for example, takes its plane off the ground in the African desert where the temperature is 110 degrees and flies immediately to altitudes at which the temperature is 20 degrees below zero.

The engine must provide wide flexibility of power instantly. In combat operation, for example, a Cyclone in a Curtiss Helldiver may be cruising along conserving fuel one minute, and a few seconds later, may be turning over at full power in combat operation. The engine must provide a range of power from on-the-ground idling to this full power in a few seconds.

The engine must be as simple as possible to maintain. On Cyclones, for example, a single cylinder may be removed without affecting any of the other cylinders; an entire engine may be replaced in an aircraft in a few hours.

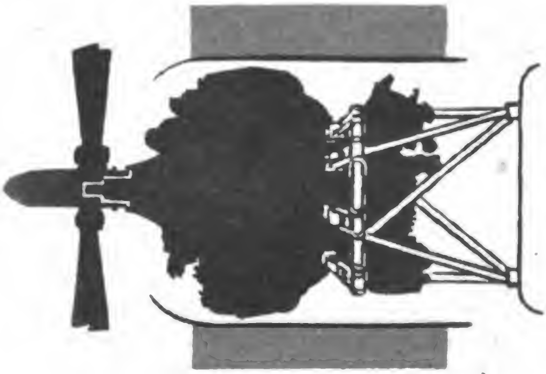
The engine must be strongly built. As a few of many evidences of this, note that a single piston must withstand a force of 30,000 pounds with each power stroke; a valve must open and close 1,200 times a minute at 2,400 rpm.



Compactness, light weight and ease of maintenance, are exemplified by this Cyclone 14.

The engine must be so constructed as to make possible interchangeability of parts. When a Cyclone 14 in a normal course of events needs new piston rings, standard dimensions must be such that rings can be taken from the stock pile.

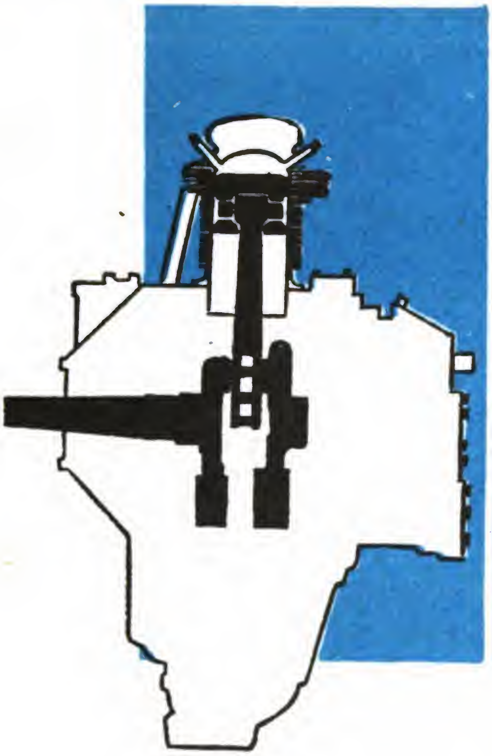
In addition to all these virtues, the aircraft engine must be so constructed as to make possible easy starting, quick warmup, fuel economy, efficient lubrication, adequate cooling under a wide variety of conditions, and full efficiency at all possible flight positions.



Wright Developed Dynamic Suspension

No. 5 — How the Crankshaft is Turned

To understand how engines such as Cyclones and Whirlwinds work, it is essential to picture the special manner in which the radial power plant makes its energy revolve a crankshaft — the crankshaft in turn revolving a propeller. The energy, as explained in an earlier chapter is derived from the rapid combustion and expansion of the gasoline and air mixture within the cylinders.



Cross section showing arrangement of crankshaft and master rod

The mechanism which receives the forces of these rapid expansions is composed of certain parts:

Pistons, each of which fits the circular space within a cylinder so that the pressure developed by the rapidly burning gas-air mixture cannot escape and must press with full force upon the top surface of the piston. As with the piston of a steam locomotive, the radial engine piston is ruggedly linked to a straight piece of rigid steel known as a **connecting rod.** In the case of Whirlwinds and Cyclones, there are two types — **articulated rods** and **master rods.** In a single row engine such as a Cyclone 9, there is one master rod and eight articulated rods. In a double row engine such as a Cyclone 14, there is one master rod for each row; the other twelve rods (six in each row) are articulated rods.

A **wrist pin,** like the pin that goes through a common door hinge, links the "art" rod, as well as the master rod to the inner structure of the piston. As with the pin in the door hinge, too, the wrist pin permits the rod to move freely with the pendulum-like motion that comes from having one end moving through the arc of a turning crankshaft.

Continuing the path of power, follow the rod to its other end—the end which gives the crankshaft its revolving motion.

Right here an important difference between the radial and the in-line engine is apparent. The in-line engine's cylinders, as related in an earlier chapter, are

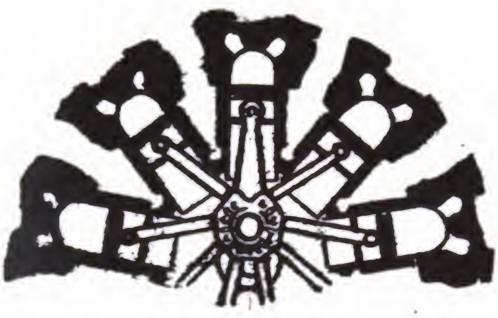
Master rod

arranged one behind another, each cylinder in a separate vertical plane along the crankshaft. Therefore, the connecting rod of each cylinder is linked to a separate crank of the in-line engine's crankshaft.

With the radial engine, each row of cylinders is ranged in a circle; viewed from the side at right angles to the crankshaft, all the cylinders in any row are in the same vertical plane. Necessarily, then, the nine cylinders of a Cyclone 9, for example, must contri-

bute their power to but one "throw" or section of a crankshaft.

The master rod and articulated rod assembly is the means of giving



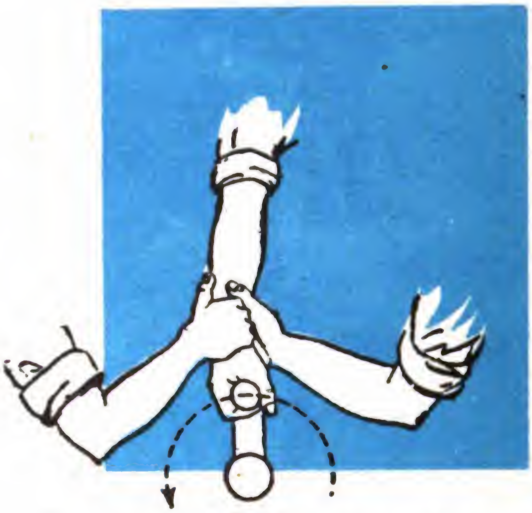
Master and articulated rods

all this power to one throw of the crankshaft.

Think of nine hands trying to turn one crank on a grindstone. The hands (like the ends of the articulated rods) would be hopelessly crowded, all trying to squeeze on the one crank handle. They would get in one another's way. The efficient manner would be to let one hand grip the handle —then let the other hands contribute their energy to the one directly connected hand.

That's the principle of the master rod. As its name implies, it is the "master" of all the rods—the collector of all their total power. No free-rider, the master rod itself is linked at its small end with a piston in exactly the same manner as an articulated rod, and delivers exactly the same share of power as an art rod.

The "big end" of the master rod connects directly to the crankshaft. Around that big end are holes — one for each of the art rods. The art rods, like spokes of a wheel, are coupled to those holes by knuckle pins. Like the hands that help another hand turn the grindstone handle, the art rods push against the separate sides of the master rod's big end, and multi-cylinder power is the result.



Principle is like that of many hands turning a single crank

Built into the compact cylinders of a Cyclone 14 is a cooling area of some 580 square feet—or considerably more than the area of a pair of bowling alleys.

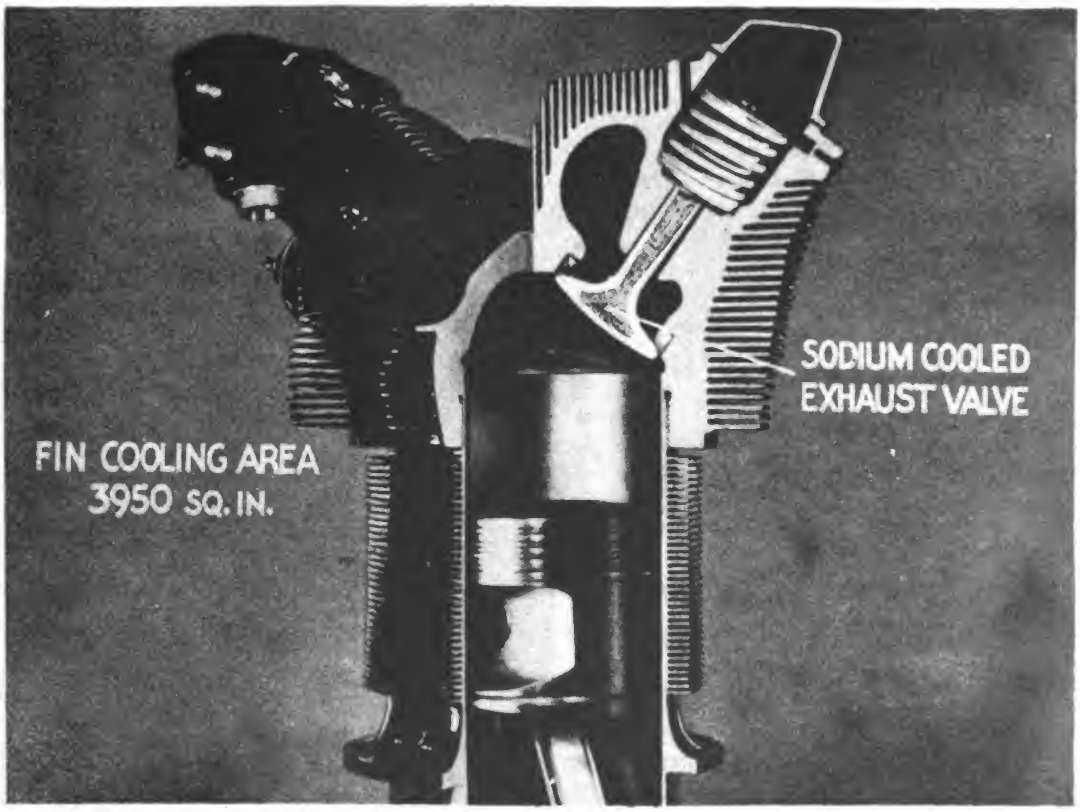
No. 6 — The Exhaust Stroke

Having studied the general mechanics of the four-stroke principle, it may be of interest to take the separate phases of engine action apart for more detailed examination.

The exhaust stroke, scavenging the cylinder of exhaust gases and thus paving the way for the next four-stroke cycle is of great importance. This is an upward stroke of the piston, it will be remembered; previously, the power stroke has resulted in pushing that piston under tremendous pressure to the bottom of its stroke, producing considerable heat and exhaust gases.

As the piston starts to rise on the exhaust stroke, the cam mechanism, operated by engine power at less-than-crankshaft speed, causes the exhaust valve to open. The intake valve, meanwhile, has been tightly closed by the valve spring. Thus, the exhaust gases, pushed as in a force pump by the piston, must crowd into the top of the cylinder and leave by way of the only opening, the exhaust port.

Even in such highly efficient internal combustion engines as Cyclones and Whirlwinds, the full potential energy in the gas and air mixture is not derived as power. The exhaust gases contain the product of whatever combustion has occurred, plus small quantities of unburned gas.



"Cutaway" drawing of Cyclone cylinder shows the exhaust valve and port in detail. On exhaust stroke, burned gases of combustion are pushed out through exhaust system by way of opening made by exhaust valve in open position.

There are a number of possible types of valves for intake and exhaust in internal combustion engines. Many aircraft engines make use of the "sleeve" type valve.

Sleeve valves make use of a sleeve in each cylinder operated by a small crank in the main crankcase. Used on several aircraft engines of British manufacture, the sleeve valve opens exhaust and intake ports by a combined reciprocating and turning motion.

A great number of auto engines use poppet valves — in some cases these valves, in autos, open by rising within the cylinder, in others, they open by descending into the cylinder, their large ends in closed position becoming in effect portions of the cylinder's roof. Practically all models of American aircraft engines, including Cyclones, use poppet valves.

In Cyclones and Whirlwinds, the exhaust valve, in opening, moves towards the interior of the combustion chamber. Closing, it moves outward and becomes a smooth, tightly-fitting circular section of the combustion chamber wall.

The exhaust valve in high horsepower engines such as Cyclones is of much more complex construction than valves in most autos. In Cyclones, such valves are hollow. In manufacturing them, the dome-shaped big end, and a large part of the length of the stem are left hollow. This recess is partly filled with sodium. The sodium, in liquid form, serves to assist greatly in the rejection of the furnace-like heat of exhaust gases. As those hot exhaust gases transmit their heat to the exhaust valve, the heat passes to the liquid sodium within the valve. This sodium in turn becomes heated. Free within the hollow space of the valve, the sodium is moved back and forth with the valve's motion. As it moves away from the big end, it carries heat with it, transmitting it to the cylinder head, and to fins from which it is dissipated to the cooling air.

The Cyclone's pistons have to support a lot of weight—some 15 tons of pressure on each piston at each power stroke, equivalent to the weight of three elephants.

Starting the Cyclone—or almost any internal combustion engine—is more than a matter of flipping a switch to move current through spark plugs. The engine must be turned by some means other than that which keeps it going in full flight; in the preliminary turning, the engine "primes" itself with the combustible vapors, compresses those vapors into the confined space of the combustion chamber, and sets off the spark of ignition that puts it on its own from then on.

Many ways of starting aircraft engines have been tried. The Wright brothers started the automobile-type engine in the first airplane by an automobile-type crank connected directly to the power plant. Later—and for a generation thereafter — the common method was handpower; a husky pull was applied to the propeller, the propeller serving in that role as a starting crank, like the crank on a model T Ford.

As aircraft engines such as Cyclones grew in power, and in number of cylinders, it became impracticable to turn them by hand. Mechanical means of starting were essential. An early mechanical device was the "inertia" starter turned by a hand crank. In this device, a man turned a crank to spin a flywheel through gears, much as one might "wind up" a grindstone to high speed. When the flywheel turned at high speed, it represented a vast amount of "stored energy" useful in turning over the engine. The next step was to harness that energy for the starting operation by engaging a clutch. The clutch transmitted the turning motion of the flywheel to the driveshaft of the engine, thus cranking it through the necessary few revolutions of the starting process.

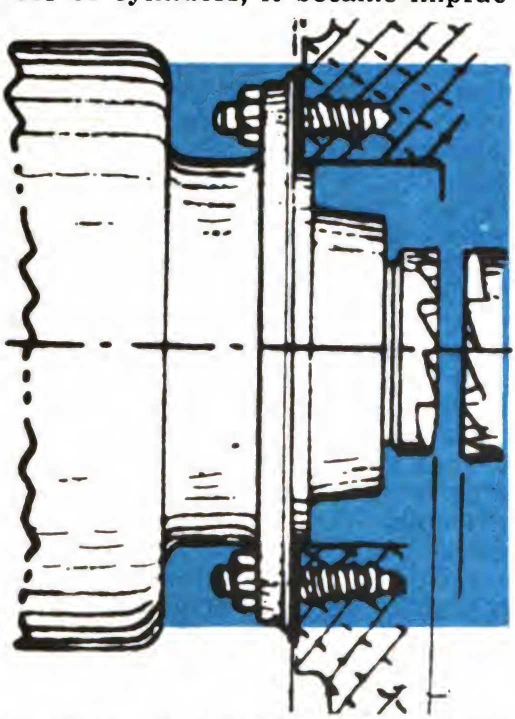


Diagram of the engaging mechanism of a typical Cyclone starter, showing the "jaws" which transmit starter force to the engine.

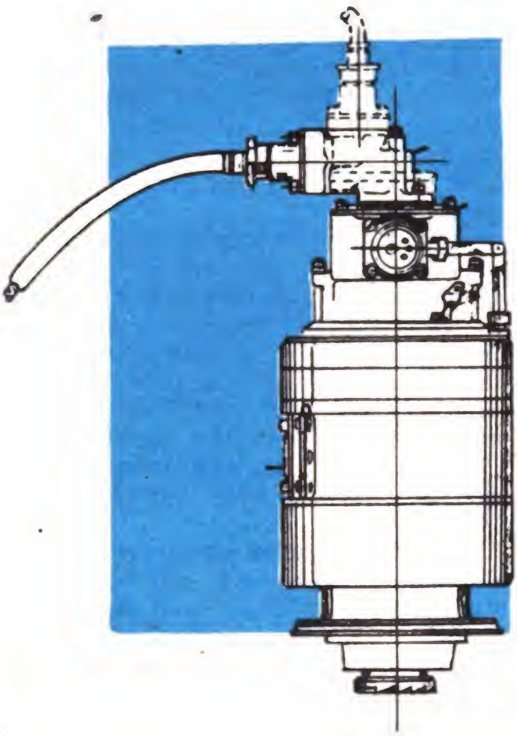
The years brought refinements to starters. The hand exerting brute force upon the crank became a hand lightly fingering a starter switch. Electricity took over. Electrically-operated starters at first were large and cumbersome, occupying much of the precious accessory space at the rear of the engine. Today they are compact, light weight.

Wright engines make use of four different types of starters. As "accessories," they are manufactured by other companies. The four types include three electrically-activated starters, and the "combustion" type starter. The latter, used extensively on engines mounted in Navy planes, employs a shell as motive power. Inserted into the starter breach like a shell into a shotgun, the starter shell is discharged electrically; the expanding gases thus generated drive a piston-and-spline mechanism which provides the initial turning force.

Electrical starters include a motor-driven inertia starter—much like the one described earlier in this story; but an electric motor replaces the man. Another type is a combination inertia and direct drive; in this device, the electric motor continues to crank the engine after the stored energy of the inertia feature has been exhausted. Finally, there is the direct

cranking starter. Here the swift turning of the electric motor is channelled directly to the engine through a system of gears and the starter clutch.

Vitally important with all starting devices is the clutch mechanism, one type of which is illustrated here. The clutch consists of two sets of "jaws" built into circular plates. One set of jaws is mounted upon the engine side; the other is on the starter. The jaws on the starter are made to



Plan of the starter illustrated with this story, showing flexible shaft through which starting force could be supplied by hand cranking if necessary.

engage those of the engine either mechanically or electrically. They are "one way" jaws. The jaws of the starter can transmit power to those of the engine but the engine cannot transmit rotary motion in return. When engine speed exceeds that of the starter, the jaws on the engine side serve to flip the starter jaws back along the starter shaft out of harm's way. The clutch mechanism serves two purposes; it transmits power from starter to engine, when the power is needed; it provides a means of preventing the starter and the engine from damaging one another.

The facts about Cyclone engine starters show the advances made in that field. Compare them with the facts about a man laboriously turning a hand crank, or spinning a propeller! The Cyclone starter weighs from 25 to 50 pounds. Its electric motor, turning at speeds from 10,000 to 30,000 revolutions

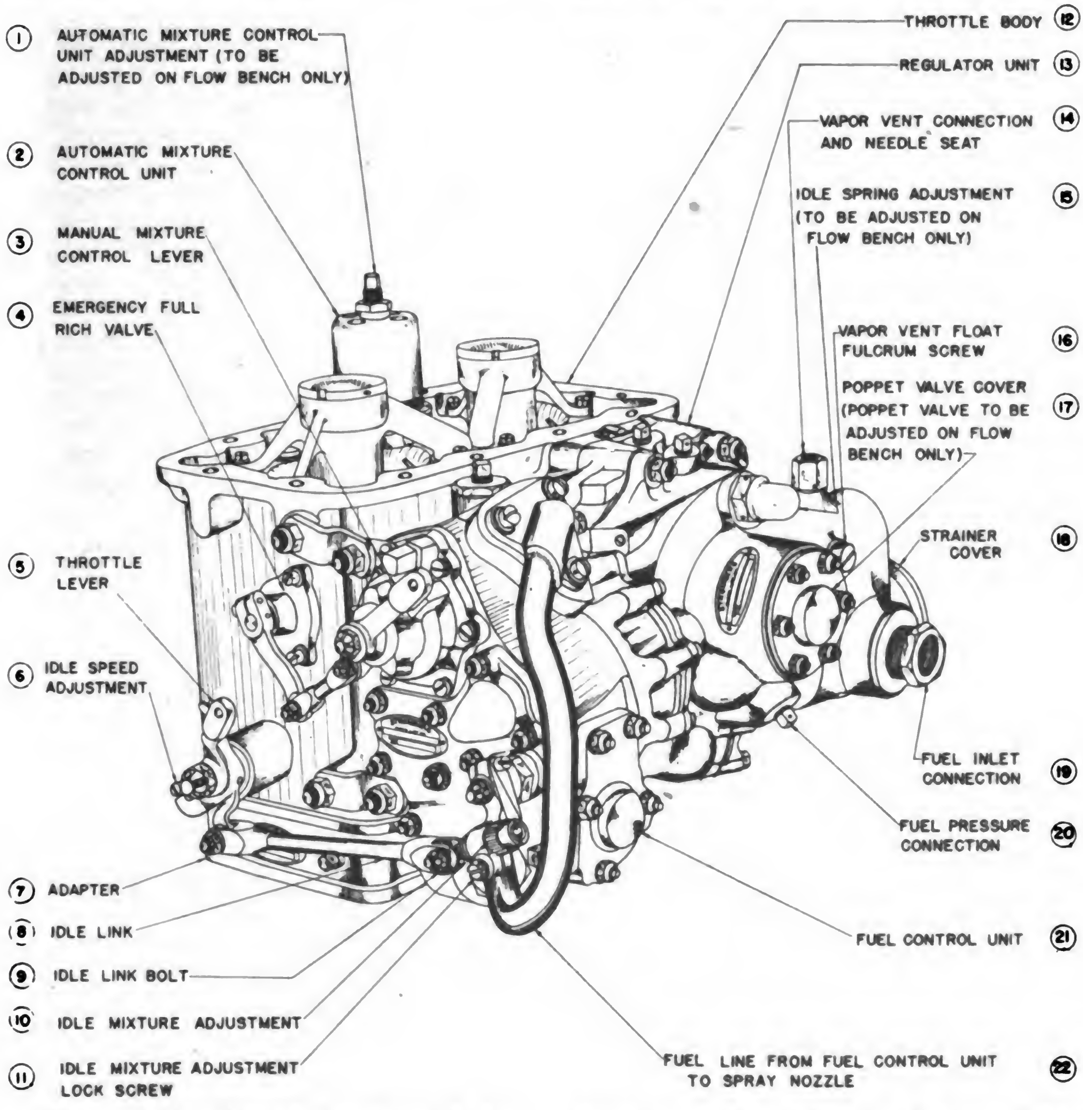
Typical Cyclone starter, compact and light in weight. This model is made by Jack and Heintz, Inc.

per minute, develops as much as 17 horsepower, the motor whirling around 200 to 300 times as fast as the engine turns in the starting operation. Usually, an aircraft engine such as a Cyclone makes five complete crankshaft revolutions before it "catches hold" for the start.

In the starter field, Wright Aeronautical has worked closely with the starter manufacturers. It is a type of collaboration that works with many other engine components not produced within Wright plants. The starter firms develop the equipment; Wright technicians tell them what the engine needs in the way of a starter. More than that, Wright engineers attempt to get under control conditions which may adversely affect engine starting. Right now, for example, Wright Aeronautical is doing considerable original research on cold weather starting, studying engine performances in test cell laboratories where an artificial Arctic as extreme as 60 degrees below zero is created. At that temperature, the starter's job is a tough one. Gasoline refuses to vaporize. Grease becomes glue. The electric battery that supplies current to the starter has less than five percent of its warm weather output.

No. 8 — Principles of the Carburetor

Since the internal combustion engine must feed itself carefully measured amounts of fuel, must keep that fuel flowing, convert it into vapor and mix it with air, engines such as Cyclones and Whirlwinds must include in their working mechanism a device to do these important jobs. That device is the carburetor.



Essentially the carburetor is an atomizer. Very early in the history of internal combustion engines, this carburetor was at one stage nothing more than a sponge soaked with gasoline and placed in such a manner that a flow of air would carry the gas vapor rising from the sponge into the intake manifold of the engine. In another primitive version, the carburetor was a shallow pan across which air was blown, again picking up the gasoline vapor en route.

Became More Complex

As more and more was learned about introducing fuel into the engine, the primitive devices were dropped. Carburetion became a function set into action automatically by manipulation of an accelerator or a throttle. In its mechanical form, the carburetor came gasping into existence in automobiles. The first aircraft carburetor, as used on the Wright brothers' plane, was merely an automotive type carburetor, somewhat adjusted to compensate for sudden changes in the attitude of the aircraft.

Today, the aircraft carburetor and the automobile carburetor have

long since moved along different roads. The automobile carburetor is not too much more complicated, but the aircraft carburetor has become a precision mechanism as accurately built as a fine watch and as self-contained as the engine itself.

The aircraft carburetor has five distinct systems: (1) a main fuel metering system; (2) a power enrichment system; (3) an idling system; (4) an accelerating system and (5) a mixture control system. The aircraft engine carburetor, through these systems, must adjust itself to provide the proper mixture of air and fuel to the engine uninterruptedly at all altitudes, engine speeds, engine loads, air temperatures and air density. As indicated elsewhere, in a discussion of the mixture of fuel and air going through the engine, density is a most important factor in carburetion; the supercharger joins forces with the carburetor to maintain the correct density of fuel and air mixture.

Air and Fuel Mixed

Air enters the carburetor either by the action of the supercharger or the pump action of the engine's pistons on the intake strokes. The amount of that air is controlled by the throttle. The amount of air is further measured by the "venturi" construction within the carburetor. This venturi principle, most important in the proper function of any carburetor, will be explained in a later chapter.

The fuel, meanwhile, is moving into the carburetor by action of a fuel pressure system. Arrived within the carburetor, the fuel is doled out for mixture with air by a device called a metering jet. The size of the opening of the metering jet and the fuel pressure on the jet determines the amount of fuel which will come through. Linked with the mechanism for introducing fuel and air in the aircraft carburetor are other devices which make possible operation at varying conditions. For example, when throttles are opened suddenly, the fuel in the carburetor which is being metered lags behind the air supply change. An accelerating pump corrects this condition by providing an additional supply of fuel at such times to maintain the correct proportion with the air.

No. 9 — The Piston and the Cylinder

While every part of an engine is important and no part is unnecessary, the team of piston and cylinder is the source from which the power springs in mechanical form to drive the swift-revolving crankshaft.

As noted in an earlier chapter of ENGINOLOGY, the combustion of the gasoline and air mixture takes place within the cylinder.

With rapid combustion comes a rapid increase in pressure of the gas and this is immediately followed by expansion of the gas against the piston which delivers its share of power to the crankshaft.

A total of 125 h.p. or more is produced by a single Cyclone cylinder. This output results from pressure of the expanding gases—about 15 tons. That 15 tons of pressure, through the cylinder and piston and the mechanism linked with the piston is translated into horsepower.

Barrel Is Cylindrical

The Cyclone cylinder is composed of the cylinder barrel and cylinder head. The barrel is the cylindrical container in which the piston rides up and down.

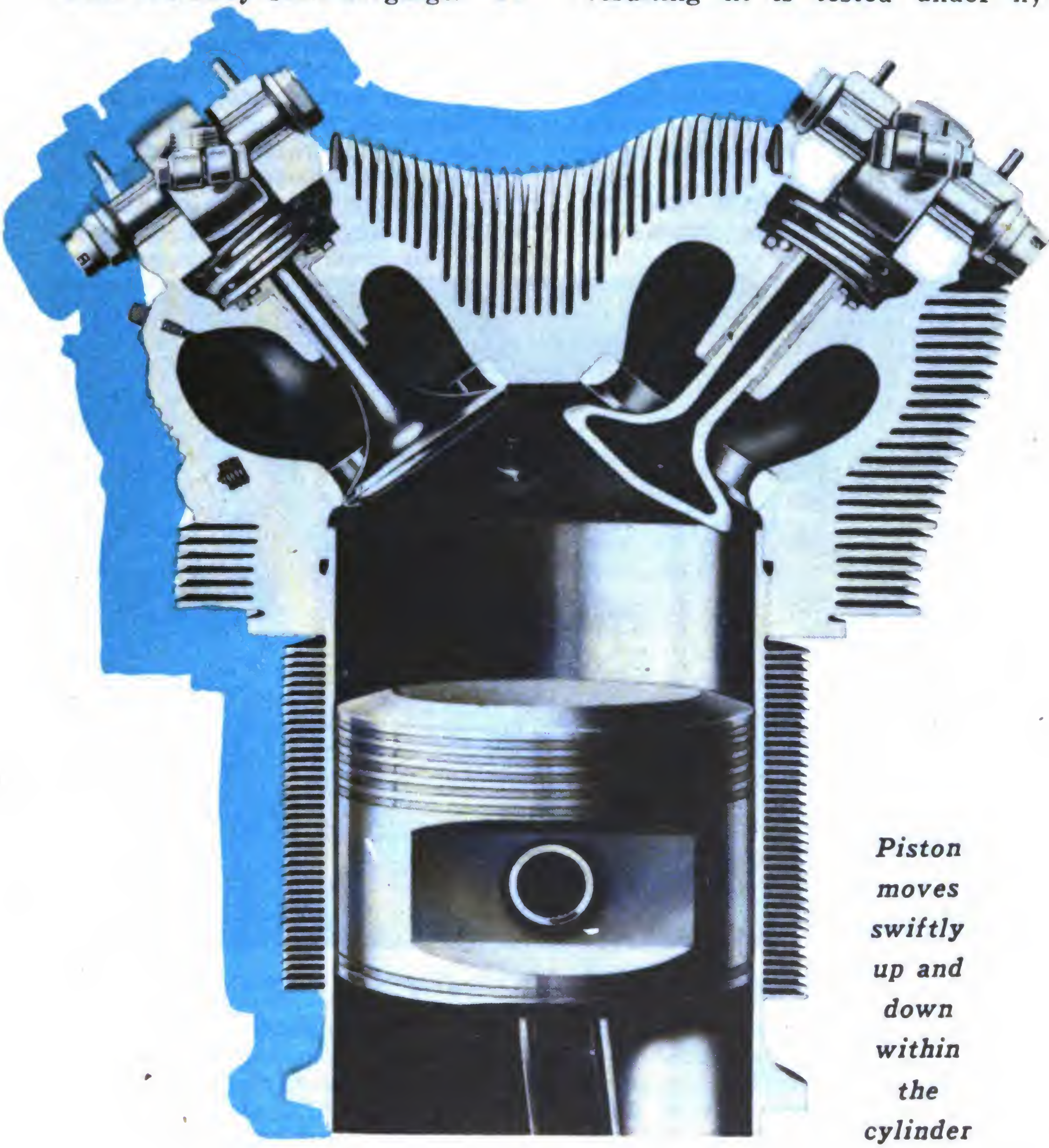
The head is the aluminum alloy structure which serves as a leakproof "cover" for the barrel. It is provided with intricate finning as a means of cooling by the air stream constantly moving among those fins when the engine is operating.

Product of 20 years of craftsmanship, the cylinder head fin structure presents to the air stream a net cooling area of more than 2,500 square inches—the area of a floor in a large living room. The fins are cast (machine cut in the case of the new forged heads) to

depths of more than two and a half inches, and spaced closely together.

Machined from Forgings

Cylinder barrels are machined from Nitralloy steel forgings. To



Piston moves swiftly up and down within the cylinder

provide still more area for cylinder cooling, close-spaced fins only .025 inch thick are turned into the barrel; these alone give the cylinder an additional cooling area of more than 1,000 square inches.

Internal walls of the cylinder barrels are nitrided to obtain the hardest steel surface ever commercially produced, thus giving the engine high wearing qualities where the piston is constantly moving back and forth.

To fasten the barrel to the head in its leakproof connection, a specially-designed thread is closely ground into the two parts. The resulting fit is tested under hydraulic pressure of 2,500 pounds per square inch.

In the piston, too, cooling fins are an important feature. The fins are milled into the aluminum alloy forging from which the piston is made, milled into the inside walls where they actually contribute to the strength of the piston. In that position within the piston, the fins make it possible for the piston to make use of oil as an aid to cooling.

No. 10 — The Ignition System

A.—The Harness

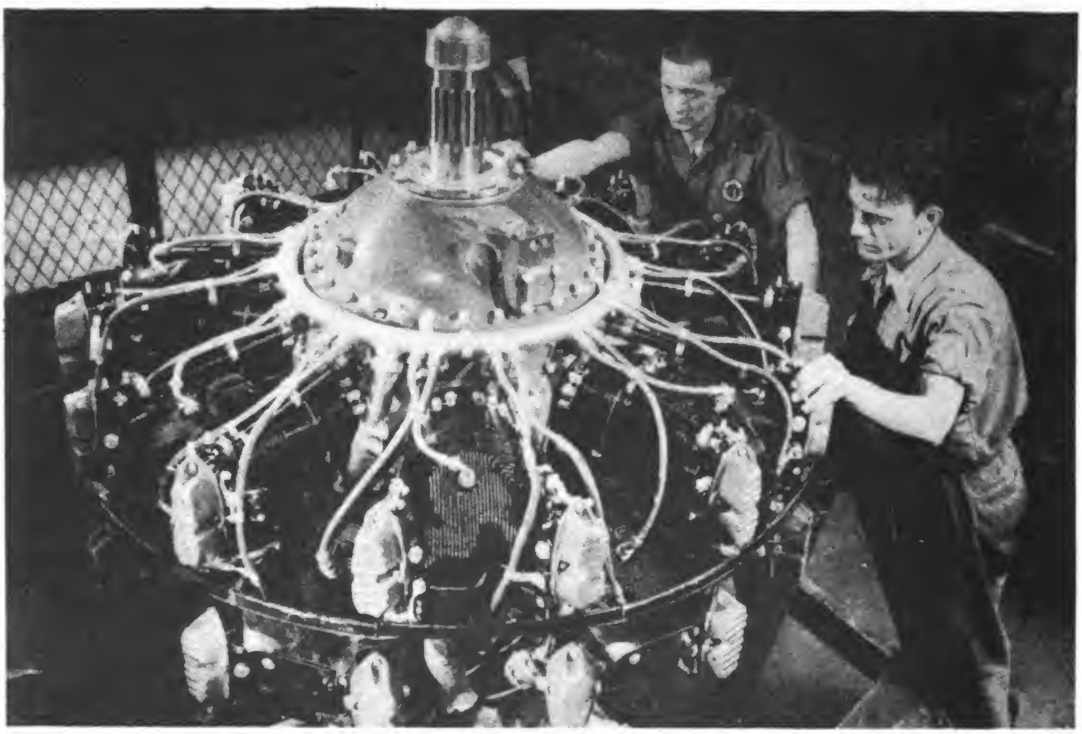
As explained in an earlier chapter, a spark produced bv high voltage electricity sets off the combustible mixture of gasoline and air within the engine's cylinders. With the rapid burning of the gas-air mixture comes rapid expansion; the expanding gas creates the power.

In a sense, therefore, this intense spark of ignition is one of the raw materials from which aircraft engine power is made. Like the other raw materials (gasoline and air) the electric current must have its own special system for bringing it to the place at which power is produced.

The Cyclone engine's electrical current, as in most other aircraft engines, is created by magnetos—two per engine, for both safety and efficiency. Each magneto sends its current to the spark plugs by way of separate wires. This "dual ignition" uses two spark plugs in each cylinder. Both plugs in any one cylinder fire for each power stroke.

Of tremendous importance in the ignition system is that part known as the "ignition harness." The harness is the system of electrical conduits which carry the current from magnetos to spark plugs. At first glance the harness may seem to be nothing more than a system of wires—like the wires in a doorbell circuit. But consider what the ignition harness must withstand in carrying the current the comparatively short distance through the snakelike course to the spark plugs. The job of the harness is twofold: it must keep the electric current inside, confine it to the inner copper wire; second, it must keep moisture, oil, cleaning compounds and air on the outside. One might add a third, as a problem common to the development of every component of an aircraft engine: it must be as light as possible; all ignition harness problems could be beautifully solved in a half-hour by enclosing ignition wires in heavy steel pipes — but such a design would undo a portion of the work of engine weight reduction.

Beginning with the problem of



Ignition harness is installed in Assembly

keeping the electrical current within the ignition wire where it belongs, one can logically think of this current as a stream of water running under tremendous pressure through a pipe. Electrically, the pressure is indeed vast, as much as 10,000 volts. It must be large to enable the surging current to jump across the spark plug gap of .012 inch. By the time spark plugs are ready to be reset, this gap has been worn away to .020 inch.

To take care of the electrical requirements, therefore, the ignition harness must provide wire adequate to carry the high-voltage current. Also, since the continuous rapid sparking creates an electrical condition which, unchecked, cannot help but be picked up by radio apparatus, the conduit is "shielded." The shielding consists of an outer metal sheathing surrounding the rubber and fabric insulation of the inner wire. The outer shielding carries no current to the spark plugs, but serves as a "ground" to conduct away the impulses which would otherwise escape into the air and be picked up by the radio equipment.

Oil Damages Insulation

Heat, weather, and the variety of liquids which play parts in an engine's life are foes to smooth delivery of the ignition current. Oil is bad for the inner portion of the ignition harness because it breaks down the rubber insulation. Moisture is bad because it conducts electricity. Most cleaning compounds used on the outer parts of the engines are, like oil, damaging to the rubber insulation.

The ignition cable, for all of these reasons, must be contained in an outer sheathing not only moisture proof but as airtight as possible. Cyclone engines make use of a specially-developed airtight brass tubing like a soldered bellows. This spiral winding of brass, covering the inner rubber-insulated wire, is, in turn, covered by an outer braided sheathing of bronze wire. In Cyclones, terminals connecting ignition harness cables to spark plugs are double-sealed, precautions here including tips of a ceramic-like material made of glass compounded with mica.

On the development side of this subject, Cyclone-builders are entitled to credit for many advances in the making of aircraft engine ignition harnesses. Wright Aero technicians, working both independently and with manufacturers of the equipment, helped to develop the metal "bellows" type of airtight sheathing. They helped to devise equipment which would withstand the increasingly high voltages; as engine power goes up, the voltage necessary to jump the spark plug gap must rise, too.

The why and how concerning the ignition harnesses is also important. To maintain the impregnability of the harness against current leakage and weather, the harness must be as carefully handled in manufacturing and installation as any other engine parts.

No. 11 — The Ignition System

(B) Principles of the Magneto

Connected to the ignition harness, and supplying the current that creates the sparking of ignition, is the magneto. On each Cyclone engine, there are two of these magnetos. There are two because the sparks from two plugs in each cylinder (one plug in each cylinder served by each magneto) provides a more efficient means of burning the fuel-air mixture than one spark. There are two magnetos, moreover, because of the safety factor — in a war plane, for example, the other magneto will continue to function independently, if one member of the team is shot out.

The magneto is a current generator. Its principle of operation

has long been known. That principle is basically the same as that which sends current surging along wires from a powerhouse to a bridge lamp; or sends current from a hand-cranked generator through one pupil to another in a science class.

To grasp the principle, it helps at the outset to remember that the

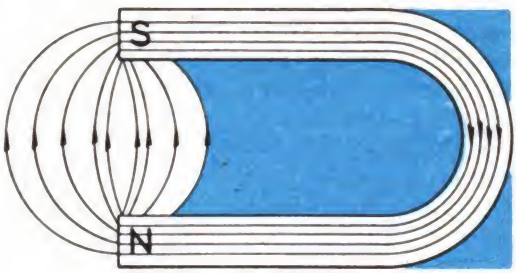


Fig. 1

phenomenon of magnetism is closely related to electricity. By the appropriate design, electricity can be converted into magnetism—as in the case of an electric magnet crane; magnetism can be made to produce electricity. The latter case applies to the magneto.

In the functioning of an ordinary horseshoe magnet (fig. 1), it has been found that magnetic lines of influence or "flux" lines run through the magnet from its "south pole" to its "north pole." The flux lines jump through the air, as shown in the diagram, continuing the chain of magnetic in-

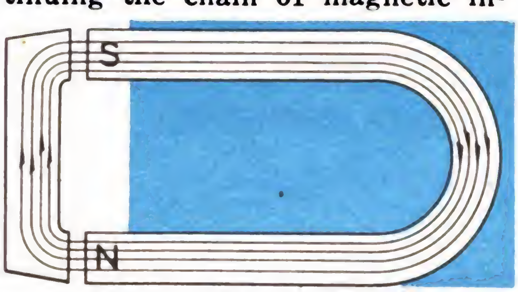


Fig. 2

fluence across the gap. Place a bar of laminated soft iron across that gap, as in fig. 2; the lines of flux finding a better conductor, will then travel through the metal.

Continue the evolution of the magneto, now, by winding wire around a bar of soft iron between the two poles as in fig. 3. Connect the two ends of the coil of wire, as shown, to an instrument known as a galvanometer. This is an instrument which indicates the direction of a current of electricity.

Demonstrating the production of electrical current in the coil of wire by means of this bar magnet, note in fig. 3a that moving the bar magnet over the coil of wire creates current going in one direction; moving it backward, away from the coil, creates current in the other direction.

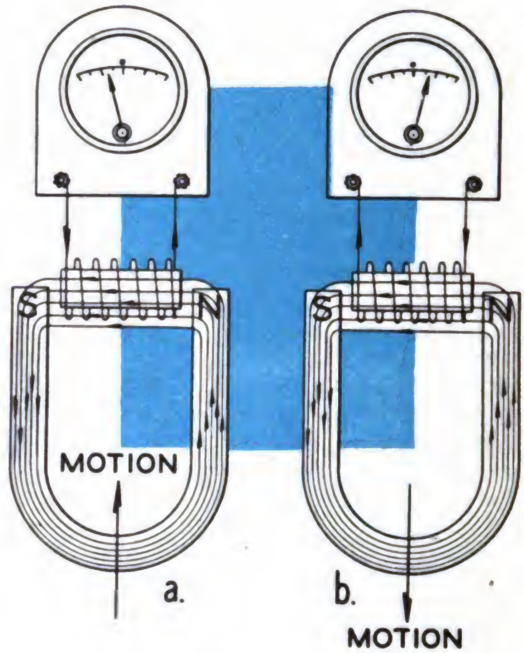


Fig. 3

Here then, is the starting point to an understanding of the magneto: current is created by **motion** of a coil of wire through a magnetic field — or, what amounts to the same thing motion of the magnet within a coil of wire.

To produce directly the potentials of up to ten thousand volts required to set off sparks in Cyclone combustion, the magneto would need to contain such a large magnet and so many turns of wire that its weight would be prohibitive in an aircraft installation. Therefore, in Cyclone ignition — as in the ignition systems of most types of aircraft engines — the magneto serves as the source of current supply. An additional device, the transformer coil, serves as a "booster" to raise the voltage to the appropriate level.

(C) Developing Voltage

Having shown how it is possible to produce electrical voltage by moving a coil through a magnetic field — or the magnetic field within range of a coil — the next question that comes to mind is: how is enough current generated to handle the large assignment represented by the ignition sparking in as many as 18 cylinders?

That job of the magneto in the aircraft engine is a large one indeed. A laboratory generator used to slightly shock the students in a science class may develop 50 or 100 volts. To cause the spark to jump the spark plug gaps under the vast pressures within a Cyclone cylinder, the magneto must generate as much as 15,000 volts!

Single Coil Impractical

In the explanation of principles in an earlier chapter, it was shown that current can be generated by moving a horseshoe magnet around a single coil. In the construction of a Cyclone mag-

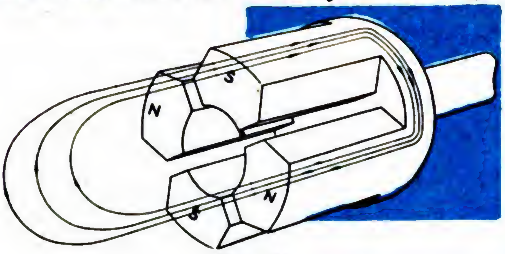


Fig. 4

neto, the single coil idea would be utterly impractical. High voltage depends upon the creation of a large number of "flux" lines (lines of magnetic influence) through a large number of turns of wire around a coil. To develop 15,000 volts with a single coil would necessitate construction of such a large coil and magnet that it would not be practical. Merely to move the magnet about the coil in such a single-coil generator would require a great deal of power.

To avoid grafting upon the engine a ponderous piece of equipment, therefore, provisions are made through which several separate magnets are caused to move within a coil or coils — or vice versa, the coil in the case of some generators moving within the magnetic field.

In the Bendix-Scintilla aircraft magneto, the magneto construction is such that the rotating member (fig. 4) becomes a four-pole magnet, with two south poles and two north poles.

Apart from the rest of the magneto, lines of flux in this four-pole magnet pass through the air from one north pole to one of the two south poles, as indicated by the curving lines in fig. 4.

Current in Coil Core

In fig. 5, the manner in which high-voltage current is developed begins to appear: with the turning

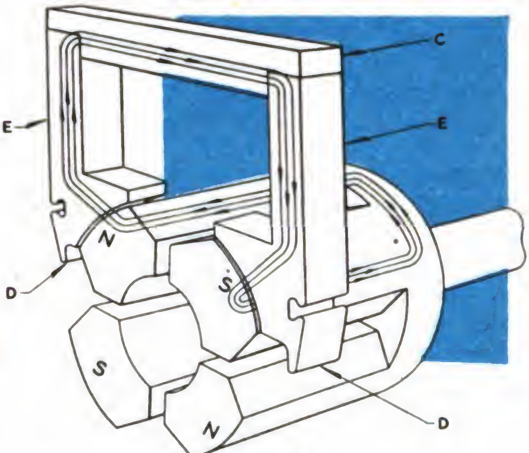


Fig. 5

of the four-pole magnet, the lines of flux, moving in their normal way, progress from the north pole through the U-shaped construction above the magnet. That U-shaped part is made up of: (D), pole shoes and (E), their extensions, together with the coil core (C). The mag-

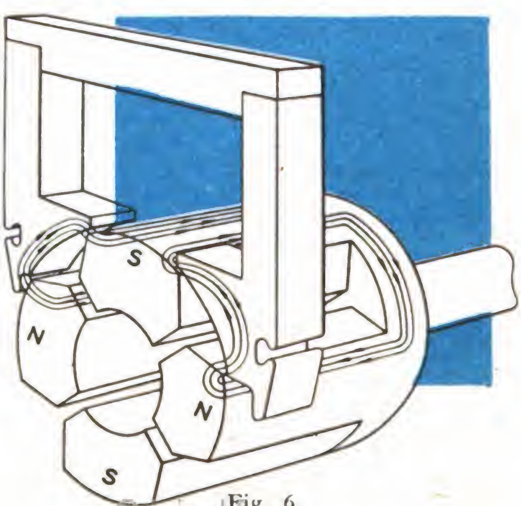


Fig. 6

netic path thus developed produces a concentration of magnetic flux in the core of the coil with the magnet in the position indicated in fig. D. As explained in the chapter on magneto principles, the lines of flux thus derived are then transmuted into electricity.

When the rotating magnet is in its neutral position (fig. 6), lines of flux do not pass through the coil. They are "short-circuited" by the pole shoes. Then, as the magnet continues to turn, the lines of flux stream through the coil core again, increasing up to a maximum as the rotating magnet is turned to its 45-degree position, as shown in fig. 5. Each time the magnet passes through a neutral position (as in fig. 6) the direction of the flux through the coil core reverses.

No. 13 — The Ignition System

(D) How the Current Is Used

The magneto, operating according to principles detailed in the last few chapters of ENGINOLOGY, is, in effect, a type of alternating current generator, modified to provide high voltage current.

What is alternating current?

It is current which flows first in one direction, then in the opposite direction; thus alternating its "polarity." To the aircraft engine it does not matter in which direction the current flows, so long as there is enough current in volume and intensity at the spark plug gap to provide ignition at the split-second when ignition is needed.

The change in direction of the current put forth by the magneto

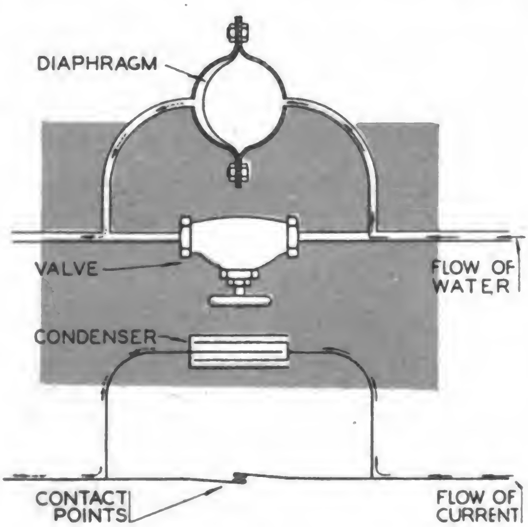


Fig. 7

is caused by the constantly changing relationship of the rotating magneto to the coil core into which the magnet's "flux" moves. In that coil core, are two separate windings of wire; the "primary" and the "secondary." The primary winding, made up of a comparatively few turns of thick copper wire, is wound directly around the coil core (see fig. 8). When the magnet is turned, its motion causes a change in the flux linkages in the primary coil. It will be remembered that an earlier chapter explained the close relationship between magnetism and electricity.

No Metal on Metal

The secondary winding, consisting of approximately 13,000 turns of extremely fine wire, is wound over the primary winding on the coil core. There is no physical connection — metal against metal—between the primary and the secondary windings.

Because of the large number of turns in the secondary winding, together with the extremely rapid change in magnetic flux resulting in a high rate of change in flux linkages, high voltage is produced in the secondary winding. Because of the manner in which the current is generated, it is necessary to provide a means of controlling the transfer, by induction, of current from the primary to the secondary windings. This mechanical equipment is the contact breaker (see fig. 8). Operated by a cam the contact breaker alternately opens and closes the primary winding circuit, thereby alternately starting and stopping the transfer of current from primary to secondary windings.

Absorbing High Current

Installed in combination with this contact breaker is another piece of electrical equipment known as the condenser. The condenser serves merely to absorb the momentarily high current when the contact opens to prevent the current from jumping from point to point of the contact breaker and burning the contact points. The principle of the condenser is illustrated by fig. 7.

To show the relationship of the magneto to the rest of the ignition system and indicate how the current is channeled into the spark plugs, examine fig. 8.

Fig. 8 illustrates a complete aircraft ignition system consisting of two magnetos, radio shielded harness, spark plugs, switch, and a booster magneto. One magneto is illustrated completely assembled and the other is in skeleton form showing electrical and magnetic circuits.

Grounded to Magneto

One end of the primary winding is grounded to the magneto. The other end is connected to the insulated contact point. The other contact point is grounded. The condenser is connected across the contact points.

The ground terminal on the magneto is electrically connected to the insulated contact point. A wire connects the ground terminal on each magneto with the switch. When the switch is in the "OFF" position, this wire provides a direct path to ground for the primary current. Therefore, when the contact points open, the primary current is not interrupted. This prevents the production of high voltage in the secondary winding.

One end of the secondary winding is grounded to the magneto. The other end terminates at the high tension insert on the coil. The high tension current produced in the secondary winding is then conducted to the central insert of the distributor finger by means of a carbon brush. From here, it is conducted to the high tension segment of the distributor finger and across a small air gap to the electrodes of the distributor block. High tension cables in the distributor block then carry it to the spark plugs where the discharge occurs.

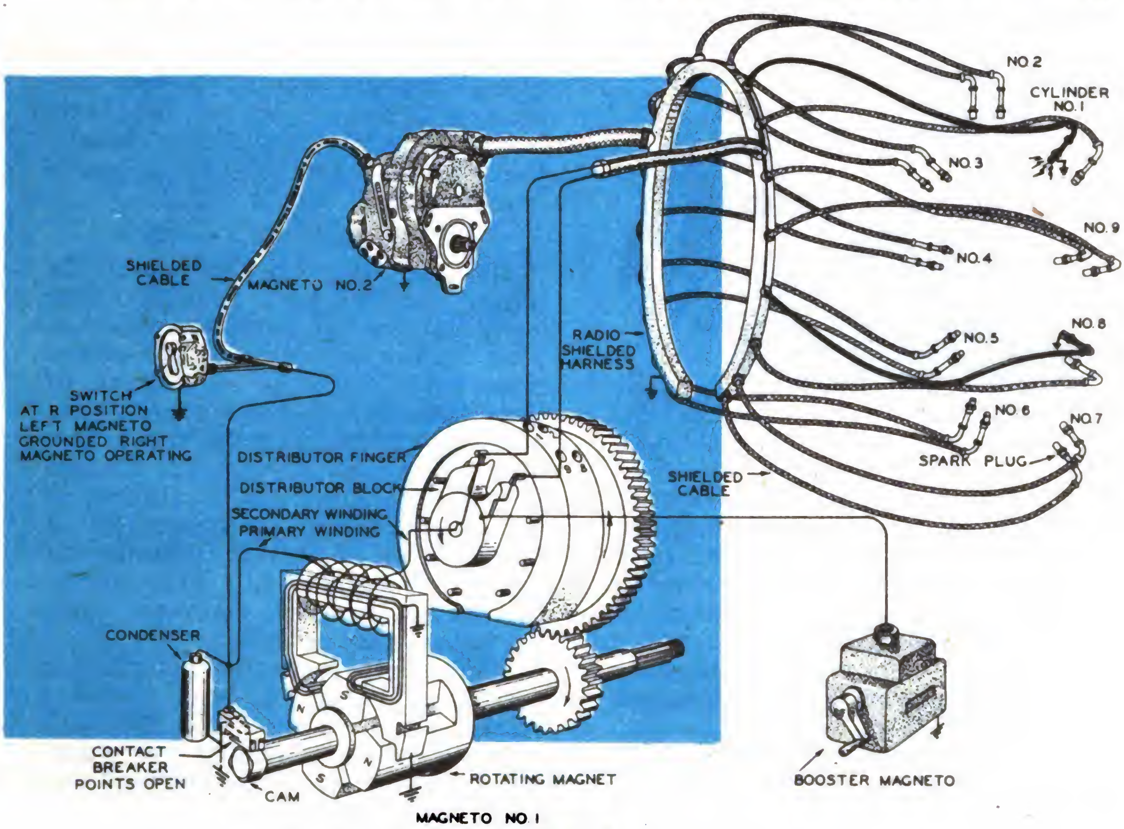


Fig. 8

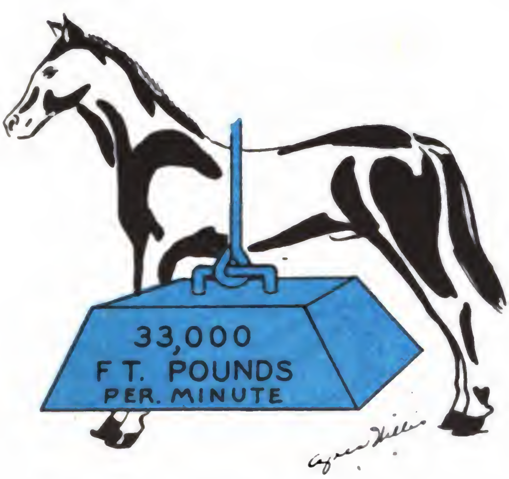
No. 14 — How Power is Measured

A Whirlwind engine working away in an M-3 tank produces 400 horsepower. A Cyclone propelling a Grumman Avenger produces more than four times as much power—1700 horsepower —while still another of the family of Wright engines provides in excess of 2,000 horsepower as one of the four power plants in the Navy's huge Martin flying boat, the Mars.

400 horsepower . . . 1700 horsepower . . . 2000 horsepower . . .

These are specific terms, measurements of propulsive force as definite as one foot is the measurement of a certain unvarying distance. These are measurements of power.

There is more to the term power than merely an ability to lift weight, to move something.

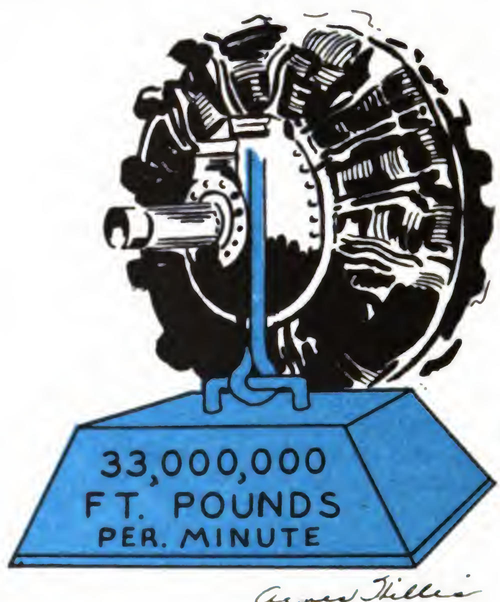


The Greek sage Archimedes once observed that a man could lift the world if he but had a lever long enough, and a place on which to rest it. But moving the earth a fraction of an inch would make Archimedes' man travel thousands of time-consuming miles through space.

Time, therefore, is a factor in the measurement of power. Weight is another factor.

Distance is a third factor in power. Archimedes' mythical man lifting the earth one-half inch, for example, in ten years, would have produced far less net work than an engine that might lift it twenty feet in the same time.

The actual measurement of power, as applied to such things



as automobile and aircraft engines, makes use of purely arbitrary terms. We use the term horsepower for no better reason than that a horse used to be man's most common power plant.

"Foot-pounds" Used

One horsepower represents the power ascribed to a brewer's dray horse back in the horse-drawn days. This "standard" one-horse's-power takes in all the three factors of time, weight, and distance. One horsepower amounts in those factors to the ability to lift 33,000 pounds one foot in one minute; in more mathematical language: 1 H.P. equals 33,000 ft. pounds per min. "Foot-pound," like horsepower, is another common term for measuring power.

The three factors—foot-pounds (distance, weight), and minutes (time)—are variable at the will of the power plant or its operator. Thus, one horsepower can be a power able to lift 66,000 pounds one-half foot in one minute, or may lift 16,500 pounds two feet in one minute. It is the

net expenditure of energy which counts.

These factors of time, weight, and distance — and the standard means of expressing all three (horsepower) — make it possible to appreciate how much power Whirlwinds and Cyclones develop. This power is measured at the factory on a dynamometer. Wright engines are not released to their prospective users unless they can develop their rated horsepower.

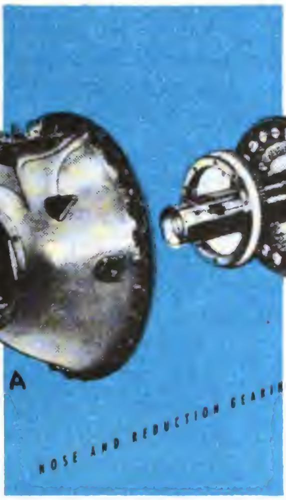
What It Amounts To

One more reference to horsepower, to understand what a Wright engine can do. Experiments have shown that a husky man can work (produce power) for a short time at a rate of about 4,000 foot-pounds per minute. Then comes the aforementioned power of one horse — 33,000 foot-pounds per minute.

Now think of that 400 horsepower, that 1700 horsepower, that 2000 horsepower! A 1,000-horsepower engine, by definition, can produce 33,000,000 foot-pounds of work per minute.

No. 15 — Arrangement of the Parts—A

Before looking further at parts which are the main components of the Cyclone engine, it is important to understand how those components are combined to form one single mechanism, the job of which is directed at putting as much power as possible behind the propeller shaft.



Looked at in terms of those separate major components, the Cyclone engine consists of such things as the following:

Cylinders, in which the power is generated.

Pistons and **articulated and master rods,** to transmit the expanding force to the . . .

Crankshaft, which is caused to revolve and turn the **propeller shaft,** either directly or through

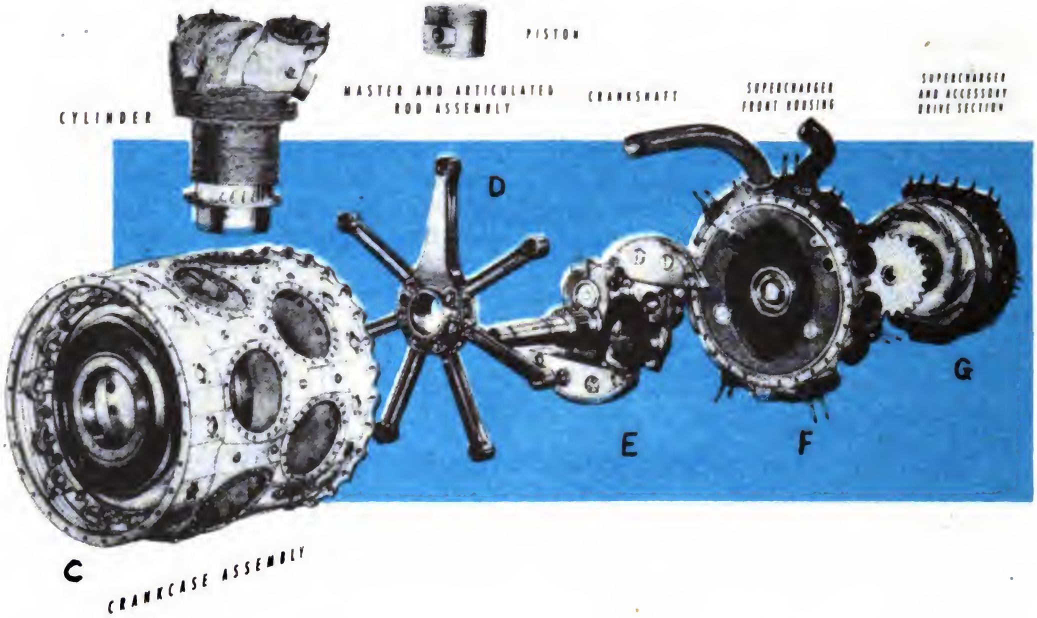
Reduction gearing, which in the case of Cyclones of the upper horsepower brackets serves to reduce propeller shaft speed to an efficient point.

The **supercharger,** which introduces air and gasoline mixture into the **cylinders** under pressure appropriate to produce maximum power.

Crankcase, nose section, supercharger housing, and **rear cover,** non-moving parts which serve as structural members, as both a framework for the engine and container for many of its parts.

In this exploded view of the major components of the 2600 B model of 14-cylinder Cyclone, the relationship of those major components can easily be seen. Beginning from the front of the engine, the **nose section** (A) serves as container for the **reduction gearing** (B); it is also the member to which the **sun gear** of the reduction gearing is attached to keep that member as explained in the chapter on reduction gears from being revolved. The **crankcase assembly** (C) is the central section of the engine, the framework to which the **cylinders** are attached by cap screws; within this crankcase assembly move the two **master rod** and **articulated rod** assemblies (D), one serving each of the two rows of cylinders and transmitting the power they collect to the **crankshaft** (E) which also moves within the crankcase assembly. The **supercharger front housing** (F) serves as mounting

for intake pipes. The supercharger mechanism includes the scallop-edged **impeller** and the **diffuser** (the vanes arranged around a central plate) at G, **supercharger** and **accessory drive sections.**



No. 16 — Arrangement of the Parts—B

Like the plaster bullfrog on the biology teacher's desk that comes apart to show how a bullfrog is made, "cutaway" models of Cyclone engines provide one of the best means of learning the construction of aircraft engines. Here is a photo of a typical "cutaway." The illustration, representing the Cyclone 9 as it would look in one stage of "dissection."

The "cutaway" and cutaway engine, built by the engine manufacturer as an important aid in instruction, is initially an original engine part or engine. Thus, the cutaway is not an approximation of that which it represents; it is the thing itself. Experts as painstaking as those who built the engine parts wield fine saws and drills and surfacing tools to cut through cylinders, connecting rods, crankcases and other components to reveal the structure underneath.

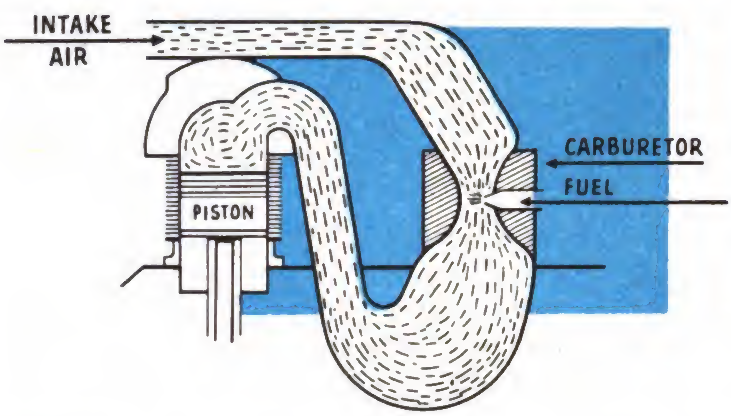
The illustration shown here, prepared by Assen Jordanoff in collaboration with Wright Aeronautical, is a cutaway that literally opens up the inside of a nine-cylinder Cyclone to show the mechanism from which power originates.

Following the numbers on the illustration for reference, it now becomes possible to see where the parts and assemblies mentioned in the other chapters fit in relation to all other parts:

Principal parts of the radial aircraft engine include such components as those numbered as follows: (1) the cylinder head, upper portion of the cylinder, much-finned structure within which is the combustion chamber where power is generated. (2) the cylinder barrel, main shank of the cylinder within which the piston moves rapidly up and down in its constant supplying of power to the crankshaft. (3) the piston and piston rings, the rings serving to sweep lubricant along the cylinder's inner walls and seal in power. (4) the piston pin, the part which connects the articulated rod to the piston. (5) the master rod, the art rod which connects directly to the crankshaft while also collecting the power of other art rods around its perimeter. (6) the crank pin, the portion of a crankshaft upon which the master rod rides (7) the counterweight, embodying the dynamic damper,

Closely related to the chapters on power (production of power, measurement of power) is the topic, maintenance and increase of power. While there are other factors contributing to the enhancement of power (such as the use of high-octane fuels,) probably the star performer in this respect is the supercharger.

When it comes to supercharging, the conventional automobile engine differs from aircraft engines such as Cyclones and Whirlwinds. Cyclones and Whirlwinds need superchargers to develop the maximum power of which their designs are capable.



The rank-and-file auto engine, operating at ground level and at 100 horsepower or less, needs no supercharger.

Begins On Ground

Superchargers are commonly thought of as devices that make it possible for modern aircraft to fly at altitudes as high as 40,000 feet. But the supercharger's story begins on the ground.

The 400 horsepower Whirlwind in M-3 and M-4 tanks is supercharged. The engines in ground-hugging attack planes are supercharged. Supercharging increases engine power even above the level attained at sea level, where the atmosphere is more dense than it is at altitude.

That factor of density is the key to the principle of supercharging.

Matter — including the gas-air mixture which burns to produce engine power—is dense when the particles (or molecules) composing it are close together, like marbles in a bowl. When those particles are separted, like the flakes in a light snowfall, the condition is not dense. It's thin.

Increases In Proportion

When it comes to engines, the power-producing ability of the fuel-air mixture increases approximately in proportion to the density.

More power is obtainable from the dense mixture, because there are more power-producing molecules of gas in the dense mixture than there would be in an equal volume of less-dense mixture.

The supercharger's job, therefore, is to create density of the gas-air mixture. For efficient combustion, this dense mixture must be composed of about 14 parts of air to each one part of gas.

In Cyclone and Whirlwind induction systems, the carburetor (supplying the vaporized fuel) is mounted just within the air intake.

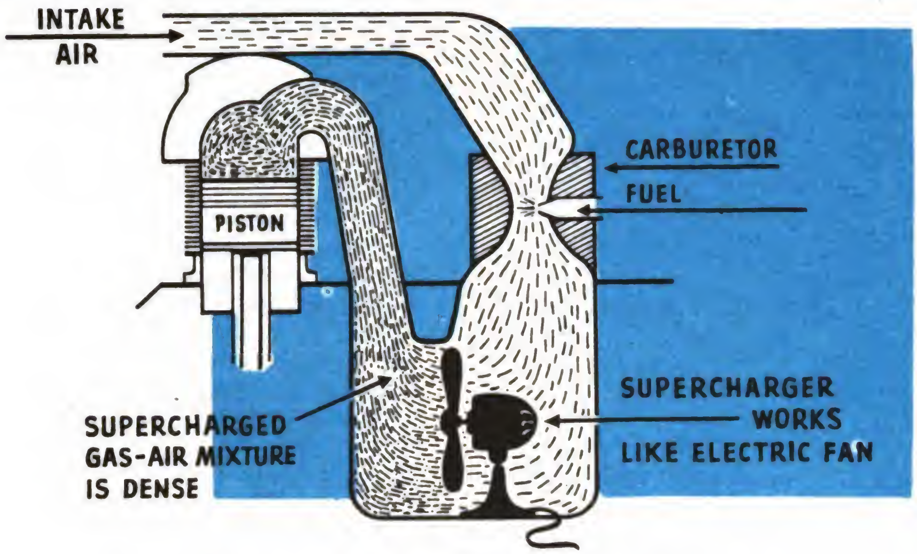
Next in line comes the supercharger, its position enabling it to draw air from outside through the carburetor — then through the supercharger itself—then on into the cylinders.

Works Like Fan

Essentially, the supercharger works like the rotary fan of a ventilating system. Equivalent to the ventilating system's fan is the multi-bladed dinner-plate-size "impeller" of the supercharger. Whirling at speeds up to 26,000 revolutions per minute, the impeller

forces the fuel air mixture into the engine.

As with a tire pump pulling a large volume of air from outside and forcing it into the confined space within a tire — the air and fuel forced into the cylinders by the supercharger is increased in density. With this increase in density comes an increase in power.



No. 18 — The Lubrication System

Rub two pieces of wood or metal together briskly. No matter how smooth the surfaces thus moved against one another, the movement cannot help but produce heat at the point of contact, and, as a result that will be noticed a little later, a wearing away of the surfaces. The cause of this heat and wear is friction. Friction as applied to the mechanics of braking, for example, is desirable. But found

Example of reducing friction: a ship, in launching, slides down greased ways

between surfaces of an engine's moving parts, friction is unwanted. Engine designers have gone to great lengths to minimize friction in engines such as Cyclones and Whirlwinds.

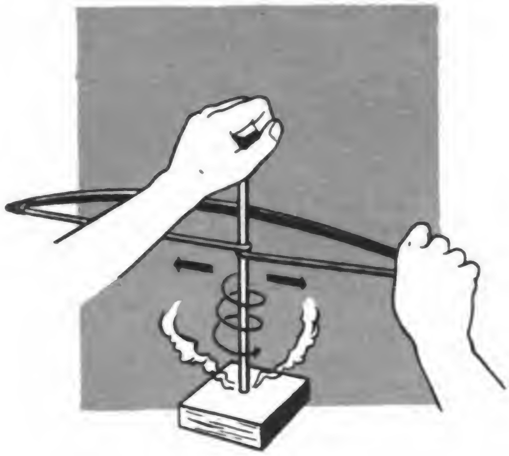
While these efforts have not completely eliminated the harmful effects of friction — they have so minimized them that a Cyclone can run for hundreds of hours with no sign of wear upon its moving parts visible to the naked eye.

Parts Move at High Speeds

Think again for a moment of that analogy of the two boards rubbing against one another as fast as a man's arms can move them. Now this is what goes on in a Cyclone engine: Operating at 2400 revolutions a minute, the crankshaft revolves in its bearings 40 times each second; each valve makes a round trip (up and down) 1200 times a minute.

These high speeds — coupled with tremendous stresses — make necessary extreme measures to keep down friction. One step that helps immeasurably is manufacturing to microscopic tolerances and fine surface finishing. Surfaces which are brought to mirror-like finishes develop far less friction in contacting other surfaces than unfinished surfaces; prove this by

first rubbing together two pieces of sandpaper, then two pieces of silk.



Example of friction production: making fire with bow and spindle.

No matter how fine the surface finish, however, lubrication is essential. In Cyclone engines, this step begins even before the engine starts to run. In the Assembly Department, for example, castor oil is brushed upon the sides of pistons before these parts are inserted in cylinders to insure that there will be lubrication for the first few strokes of test cell operation.

What does lubrication do? Fundamentally, lubrication provides a protective film between the surfaces of the moving parts. While oil circulation within an engine such as a Cyclone has a secondary function — that of carrying away some of the heat generated by the burning combustion gases—this protective film is the major purpose.

No. 19 — The Crankcase

The crankcase of a radial engine such as a Cyclone or a Whirlwind is vastly different both in shape and function from the crankcase of an auto engine. In the Cyclone and Whirlwind, the crankcase plays a major role. In an auto engine the crankcase is a partitioned receptacle attached to the bottom of the automobile's in-line engine. In most types of autos it serves not only as a structural member but as a container for engine lubricating oil, holding that oil in pools at the bottom of each cylinder to be splashed to the moving parts from there as the pistons go up and down.

Structural Member

The Cyclone crankcase, on the other hand, is primarily a structural member of the engine. Looking at it in its simplest form — as in such single-row engines as a Whirlwind or a Cyclone 9 — the crankcase is a drum-shaped part upon which all cylinders are mounted. Add another row of cylinders as in the case of a Cyclone 14 or a Cyclone 18; the function of the crankcase is still that of serving as the central framework of the power plant.

Product of Long Development

The Cyclone and Whirlwind crankcase looks simple in appearance. But, like a great many things possessing the virtue of simplicity, it is the result of years of refinement and innumerable complex studies. Earlier in its development, the Cyclone crankcase was literally carved out of large steel forgings, its separate cylinders being bolted to flat-surfaced sides. Each of the sides of the crankcase of that era had to be cut separately from the original forging.

Cyclone 9 Crankcase

As crankcase development continued, it was found possible to so change the design of the part that the forgings could be "carved" by making them fundamentally circular in shape, turning the crankcases of many engines in specially-designed lathes. With high cutting speeds made possible by lathe operation, crankcase manufacturing at Wright Aeronautical took on a mass production character even before war demands came along.

As the very core of an engine, the crankcase not only serves as the member to which cylinders are attached; it also carries within it the bearings within which the engine's crankshaft revolves. Then, too, an engine's nose section is attached to the front of a crankcase; supercharger sections are attached to the rear of the crankcase.

Cyclone 14 Crankcase

Has Many Purposes

In some Cyclone models such as the Cyclone 14, the crankcase extends forward considerably beyond the circumference of the front and rear rows of cylinders; in that extended part, the crankcase supports valve tappet guides

Cyclone 18 Crankcase

where the latter extend from the cam assembly outward to cylinder heads.

The Cyclone crankcase resembles the automobile crankcase in that it is the natural receptacle for that portion of the engine oil which collects within it as the normal results of engine oil pressure. Such escaped oil is collected in an oil sump at the bottom of the engine. The sump is a reservoir. From it a pump moves the oil back into the engine's lubricating system.

No. 20 — Valve Operating Mechanism

In an earlier chapter, explanation of the four-stroke principle indicated the function of valves. To review, briefly:

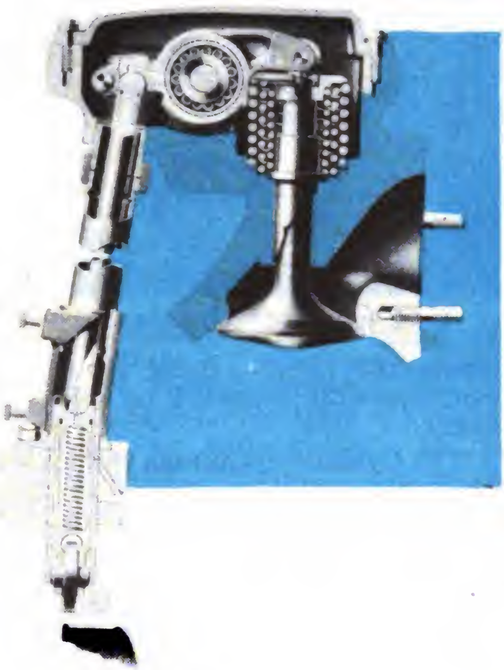
Controlling ports that open into the cylinder, the valves — one exhaust valve and one intake valve to each cylinder — govern the movement of the fuel air mixture and the burned gases in and out of the combustion chambers.

The intake valve opens for the intake stroke to make possible the entrance of the mixture of gasoline vapor and air which will be burned to produce power. The intake valve does not open and close, open and close, as the piston goes up and down, up and down. The intake valve remains closed during the succeeding events in the cycle strokes after intake. It's closed

through the compression stroke (as is the exhaust valve) so that the gases cannot escape. It's closed for the power stroke, so that the combustion gases will not blow back through the induction system. It's closed for the exhaust stroke, so that burned gases cannot be channeled out to mix with the still-unburned gas.

Opened at Exact Time

The exhaust valve, similarly, is opened only when it's time for



The valve mechanism features roller bearing rocker arms and pressure lubrication of all vital points.

The Cyclone's single piece, gear-driven cam actuates the followers for both intake and exhaust valves.

the burned gases to be expelled from the cylinder. For all other strokes, the exhaust valve must remain tightly closed.

For each valve in any one cylinder, therefore, mechanism must be provided which will open the intake or exhaust port at the appropriate time. And since each of the valves — both intake and exhaust — moves up and down only once in each four-stroke cycle, that mechanism cannot be actuated directly by the turning crankshaft.

The crankshaft supplies the power for the valve operating mechanism. Its rotary motion turns gears which, in turn, drive a single-piece cam at a speed slower than that of the crankshaft, exactly fast enough to assure valve action at the proper time. The cam is a large revolving plate-like part with teeth on the inner surface of a flange extending around the cam's outer circumference. The outer surface of the cam is not circular. There are precisely-shaped, accurately-located bulges at intervals around that outer surface. Those bulges make possible the opening and closing of the valves.

Connecting to the push rods that extend like spokes outward to the separate cylinder heads are "followers" that ride in and out as the bulges on the cam alternately push the followers and let them (through spring action) move inward again. The principle is the same for each cylinder's valve assembly:

"Bulges" on Cams

As the bulge on a cam forces a follower outward, the follower in turn moves the valve push rod with which it is connected. The push rod, in turn moves upward the outer portion of the valve's "rocker arm." The rocker arm, pivoted on roller bearings, translates the upward motion into downward motion through the pivot— just as one end of a seesaw must go up while the other end goes down. The downward motion is passed along to the valve stem. The valve, being of the overhead type, opens its port in moving downward.

Full pressure lubrication of Cyclone valve mechanism is obtained by metering a supply of oil through valve tappets and guides, into the push rods by way of the drilled ball ends, and thence through holes in the adjusting screws to the rocker arm bearings.

For various reasons, it is not always desirable to have an aircraft's propeller turn at engine speed, and this is particularly true in the case of high-horsepower engines such as Cyclone 9's, 14's, and 18's. Reduction gearing built into an engine as an integral part of the power plant is the means by which engine operating speeds are translated into efficient propeller speeds. Propellers must be designed to bite enough air to hold this engine power, and propeller-tip speed must not exceed that of sound.

At the foundation of reduction gearing is the principle of leverage. To lift up 4,000 pounds of automobile when one has a flat, one uses a jack; makes many downward motions of a handle—translates a moderate amount of force and a large distance into a greater force, but lesser distance. Distance in this case is represented by the aggregate travel of a person's hand in pushing down the jack handle, compared to the inches of distance which the car must be lifted.

Torque Vs. Speed

In the case of reduction gearing, similarly, the driving gear of the reduction gear system in one model of Cyclone 9, for example, will make three revolutions to every two of the propeller shaft. The reduction gear system has thrown away only the very small portion of the engine's output absorbed by any friction and has made it possible to increase the propeller efficiency. This results in a proportionally greater drive available to pull the airplane forward.

How does the Cyclone reduction gear system work?

Developed through the years, the reduction gear assembly is of the planetary type, so-called because a series of small gears — known as pinions — are ranged in a circle about a large central "sun" gear, much as the planets in the solar system are ranged around the sun. As with the solar system, too, those small pinions not only move in their circular orbit around the sun-gear — they also turn on their own axes as they go, much as the earth rotates on its axis as it revolves around the sun.

Follow the course of engine

power to see how reduction gearing works:

The engine's crankshaft, direct supplier of engine power, is connected by splining to the reduction gear system's "driving gear." The driving gear is the one having the largest diameter of all — it bears its teeth along its inner circumference. Those teeth are meshed with the teeth of the smaller pinions.

Pinions Ride on Trunnions

The pinions ride on shafts called trunnions which in turn are built into either spoke-like arms, or plate-like carriers. While the principle in every case remains the same, there is some variation in this respect among the separate models of Cyclones. In every case, however, carrier rings or pinion-bearing arms are connected directly to the propeller shaft. Thus, a propeller shaft with its pinion gear assembly looks like an axle

with a wheel — around the rim of that wheel (or at the ends of its spokes in the case of arms), are mounted the separate pinions.

Back to the course of power: The turning driving gear transmits its power to the separate pinion gears — these gears are meshed to the teeth on the outer circumference of the sun gear. If the sun gear were free to turn, the pinions would serve merely to transmit the power to the sun gear to turn the latter. But the sun gear is fixed, bolted to the nose section. Therefore, engine power, compels the pinions to "walk" around the sun gear, moving the propeller shaft with them as they go. The speed of the propeller shaft is less than that of the crankshaft under this arrangement because some of the crankshaft's excess turning is used up in turning the pinions around their own axes.

The system described applies to engines whose propellers turn more than one-half crankshaft speed as is the case in gears with a ratio between the crankshaft and the propeller shaft of 16 to 9, 16 to 11, 4 to 3, etc. The same system can be and is used when the prop speed is less than one-half crankshaft speed, as in the case of the 16 to 7 ratio gear, by attaching what was the fixed sun gear to the crankshaft and "fixing" the large gear to the nose section.

No. 22 — The Cowling

Having attached the engine to the aircraft in such a manner that the harmful effects of vibration are absorbed, the engineers still have a big job to do. Aircraft must be streamlined, meaning that every part of the plane must be so shaped that it offers a minimum resistance or "drag." The position of the engine must conform to that streamlining.

In the early days this drag was not considered important. The first light plane, for instance, was

Cowling shrouds this Cyclone on a DC-3

a maze of struts and wires and driving chain all fastened to the structure willy-nilly like the trappings in a circus tent. Then experiments showed that these trappings which stuck out in the open were stealing some of the aircraft's forward speed, robbing it of fuel economy and load-carrying capacity. The designers reasoned: one would not stick furniture and fittings and passengers out in the open water on both sides of a motor boat, why do it in the element through which an airplane travels?

Special Study was Needed

In this gradual trimming up of the aircraft's shape and outer surfaces, engines required very special study. The engines could not be hauled inside of the fuselage and bolted down out of the way like fire extinguishers. They had to be exposed to the air for cooling. In 1930, the product of considerable research began to appear as an answer to the engine problem. The answer was specially designed "cowling", or sheathing built about the outer circumference of engines such as Cyclones and Whirlwinds. An engineer named Fred E. Weick was responsible for the so-called "total enclosure" cowling.

Under the name of the NACA cowling, (standing for National Advisory Committee for Aeronautics) the Weick cowl, in effect, put the Cyclone and the Whirlwind in a neat package, allowing the airstream caused by the movement of a plane to be channelled smoothly around the outside of the cowl and within the cowl through the cooling fins of the cylinders. The result was a saving of at leat 50 percent in the drag hitherto caused by the mere physical presence of a radial engine on a plane. The result was also the technical advance which enabled the Cyclone and Whirlwind to compete so successfully with the "in line" engine that the airlines went all-out for the radial type in the form of Cyclones for Douglas DC-1's, DC-2's, DC-3's, Boeing Pan-American clippers, and Curtiss CW-20 Commandos.

Has Control Feature

Today the engine's cowling has been so refined that it is not merely a streamlining device. It also embodies controllable equipment for varying the amount of cooling air flowing over cylinders.

Installed on multi-engine aircraft such as modern Cyclone-powered airliners, the cowl-equipped engine has made it possible to mount the power plants "midwing" in position; in other words, neither wholly above nor wholly below the wings, but on the line of the wing chord. Without the cowl, past experience had shown, the propeller's blast or airstream was so interrupted by the wing immediately behind it that inefficiency resulted. With the air flow smoothed out by the enclosing cowl, the wing and propeller no longer react adversely.

No. 23 — Engine Baffles

In another chapter, the construction and use of the engine cowling is discussed; it is explained that this carefully-designed sheathing around the outer circumference of a Cyclone or Whirlwind serves not merely to dress up an aircraft, but also — and most important — to reduce the "drag" presented to the air by sheer bulk of the engine. The cowling channels the airstream both in and around the outer sides of engine nacelles.

That portion of the airstream which is thus channeled within the cowling, through the engine, must be further guided among the cylinders to perform its function of cooling. The equipment used for this channeling among the cylinders is the baffle assembly.

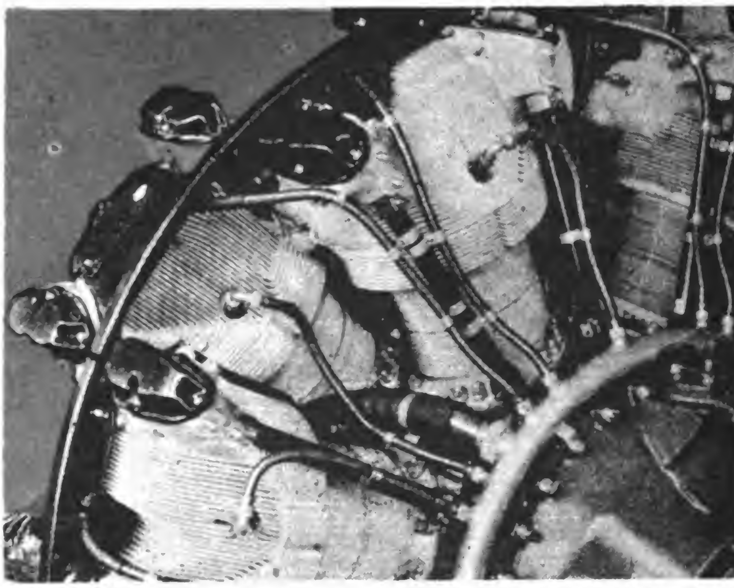
For each Cyclone 9 engine in a Douglas DC-3 for example, there are separate baffles, the total number of them making up the system of surfaces which cause the moving airstream to circulate among

cylinder fins and carry off the heat conducted out to those fins from within each cylinder.

The principal of baffling is basically simple. Hold your hand outside the window of an auto travelling at 90 miles per hour. The hand, projected into the air speeding by, becomes a baffle. While you feel the pressure of the air on

permanently installed among the cylinders can do the work of many hands more efficiently, this is the way the job is done. These surfaces are the baffles.

At Wright Aeronautical the exact sizes and curvatures of baffles are determined by the Engineering Department; each baffle in itself being not merely a bent piece of



Cylinder Baffles installed on engine

the hand, you know that the air in turn, because it does not pass through the hand, must have been deflected. If it were practicable to have many persons crowding around the engine in flight, each holding their hands so that portions of the airstream could be directed to the separate cylinders, you would get the equivalent of the baffle system. Since surfaces

metal shaped in approximate conformity with the cylinder, but a carefully made surface precisely shaped to make the most of the airstream. Baffles made for Wright engines are made in a special department which obtains the exact curvatures by pressing the sheet metal or plastic down upon master surfaces possessing in themselves the desired shapes.

Exposed View of Baffles

No. 24 — Piston Rings

In the simple pressure pump—a bicycle pump or a bailing pump, for example — the piston employed to create pressure or vacuum, as the case may be, is invariably a solid plate or cylinder of appropriate metal moved backwards and forwards by means of a rod bolted directly to that "piston".

In Cyclone and Whirlwind engines, the basic principles that apply to the simple bicycle pump are much the same so far as the mechanics of the piston are concerned. But Cyclones and Whirlwinds operate at tremendous speeds compared to the slow movement of the handle in a tire pump. Because of these tremendously greater speeds and vastly greater pressure, the part which accepts the pressure — the piston — cannot be a simple chunk of metal cut out in a shape to fit the interior of the cylinder.

The piston, an aluminum alloy forging, is in itself a complex piece of construction. In many models of Cyclone engines, the inner surfaces of the piston are intricately "finned" in one pattern or another much as the outer sides of a cylinder are finned; the purpose here is to assist the piston to carry off excess heat generated directly above it in the combustion chamber.

Piston rings are another feature

Typical piston and ring setup for a Cyclone

of piston manufacture made necessary by the conditions met inside the cylinders. Actually, piston rings are not characteristic of Cyclones and Whirlwinds alone. Automobile engines must use piston rings and practically every other internal combustion engine made for any other purpose makes use of these rings. The number of these rings, their construction, and the metal of which they are made, however, differ widely.

The piston rings serve two principal functions and in Cyclones and Whirlwinds special types of rings are provided to answer each of these two special needs.

In one of its roles, the piston ring serves to assure maximum compression. The rubber ring on a glass fruit jar used in preserving provides one analogy. Sitting in its groove in the piston and serving as the medium of contact between piston and cylinder walls, the piston ring provides the thickness of metal between piston and the cylinder wall needed to prevent the expanding gases of combustion from escaping around the piston. On the exhaust stroke it forces the burned exhaust gases out of the cylinder. The compression piston rings serve to keep the exhaust gases from getting by the space between piston and cylinder wall. As all Wright engines are built, it is important to remember that this space between the piston and the cylinder wall actually is but a few thousandths of an inch in extent but under tremendous pressure considerable engine efficiency would be lost unless this small gap was closed by the piston ring.

The piston ring serves in its other function—and other form—to distribute oil to the inner surfaces of the cylinder. Remembering that this inner surface of the cylinder is honed and polished to a smooth mirror-like finish in itself serving to reduce friction, the oil scraper rings give these surfaces the coating of oil needed to finish the job of keeping friction down to a minimum.

From one model of Wright engine to another it will be found that piston ring design is not standardized. This is because engines of different horsepower output have been found to require different types of piston ring assemblies. The average auto engine, of low power, works efficiently with but three or four piston rings to each piston. Aircraft engines in the higher horsepower category usually need additional rings.

No. 25 — Test-Running the Engine

The best way to find out whether something mechanical will run well and do the job it is designed to do —is to run it.

In the aircraft engine business, Wright Aeronautical has applied to the work of testing and inspecting, scores of complex instruments, designed not only by its own technicians, but by scientists in other fields as well. But all the information which these instruments can give cannot answer the question "Is it up to standard?" half so well as test cell proving.

Test cell operation of engines in the building of Cyclones is equivalent to the road testing of new cars by the auto industry. As with the road testing, engine testing in the test cell subjects the product to more gruelling operation than conditions generally encountered in actual service.

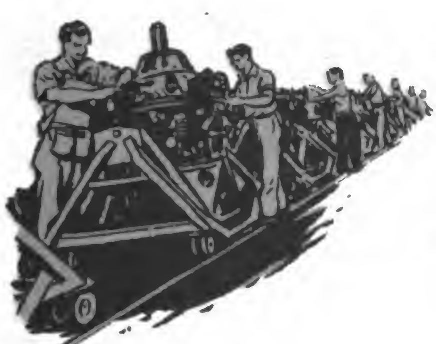
But there is this important difference: while road tests for new cars are usually confined to first models or experimental models, test cell operation is a "must" for every Cyclone which leaves the factory.

Test cells are, therefore, permanent installations in the Wright Aeronautical factory buildings. They are of several kinds. Most numerous are the production test cells. These are the chambers within which all newly manufactured engines of already-accepted design must be test-operated before being shipped to users. The other type

of test cells are known as "experimental." These are the proving grounds for engines still in the development stage — or going through one trial after another to further improve an accepted model by changes in specific parts or materials. A small but important member of the experimental test cell family is the single cylinder test cell. In the "singles," the engineers can isolate to a single cylinder the events occurring within all the cylinders of an operating engine. In the full scale engine, sometimes a cause or effect is missed because it is difficult to pin down the action in the general thunder and motion of the many parts. In the single cylinder cell, the technician is enabled to focus his attention directly upon one mechanical action at a time.

From a manufacturing viewpoint, the production test cell is but another extension of the quality-assurance activity which has followed every step of the engine's fabrication up to that point. For a Cyclone 9, for example, an estimated 36,000 separate inspection operations must be performed.

In sound-proof control room, engineer puts a Cyclone through its final test run; previously, the engine had to pass gruelling "green run."



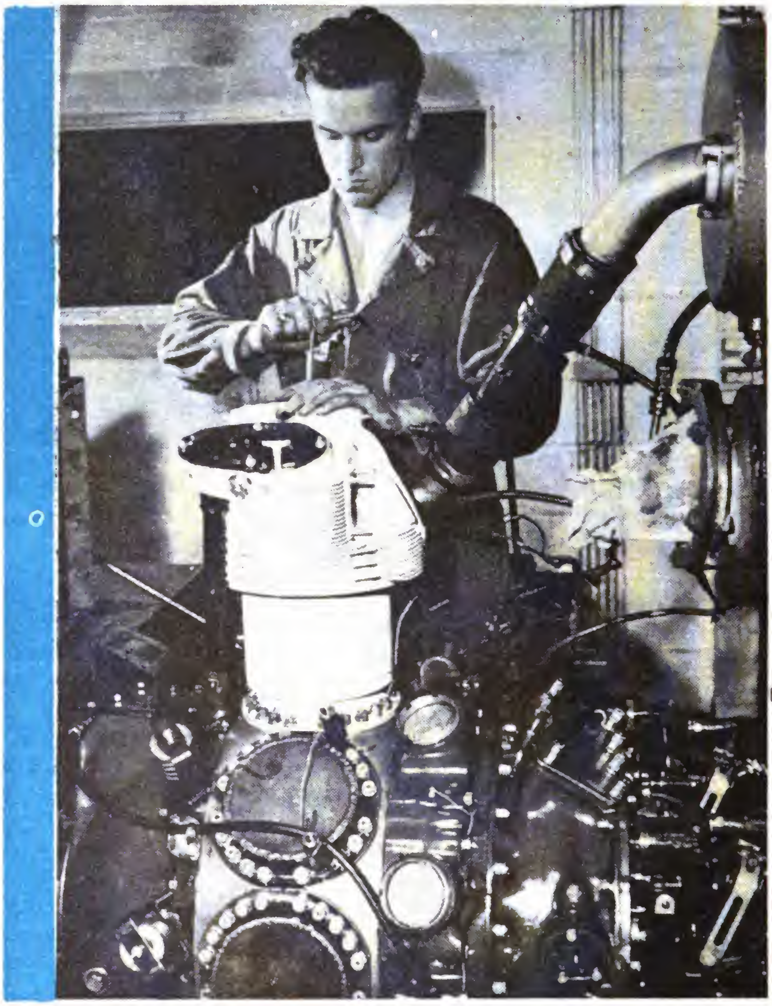
Wright developed the First Moving Engine Assembly Line

Rigged up in a test cell, the power plant thus intricately inspected should be capable of doing its work well. But nobody knows for sure—until after the test runs.

Production test operation includes two phases. First there is a "green" run of approximately seven hours. In this time, the engine is operated not only at cruising speed, but at take-off power—at speeds considered at least equal to the most severe which will be experienced in actual service.

After the green run, the engine is completely disassembled, its parts spread out for inspection which searches for the tiniest scratches or signs of wear. If this scrutiny discloses no substandard conditions, the engine is re-assembled, returned to the test cells for its "final" run—and there again subjected to a tough workout.

Each test cell consists of two parts. In the larger quarters, the engine itself is installed. Controls and electrical connections are run from the engine to the second of the two parts of the cell—the control room. Within this control room, specially-trained technicians sit at a table studded with instruments and controls. Their job is to record the story of engine operation accurately told by the instruments. Also they must observe the engine at work through a window opening into the engine compartment.



Single Cylinder Test Cells Isolate Occurrences Within the Engine, Give Chance to Focus On Details

No. 26 — Wright Whirlwind R-975

Among the "junior members" of the family of Wright engines, probably the most famous at this point in aviation history is the Whirlwind R-975 engine, the power plant which drove the M-3 and M-4 tanks across the deserts in the armies that chased Rommel out of Africa. The Whirlwind continues in use in present action, its performance as the propulsive force for ground vehicles demonstrated already in tens of thousands of miles of rumbling, dusty action.

The Whirlwind, to be sure, preceded the Cyclone in the family of Wright engines. Back in the late 20's the "J" series of Whirlwind engines, was making history with such feats as the flight of Lindbergh's plane across the Atlantic, and Byrd's plane "Southern Cross" to the South Pole.

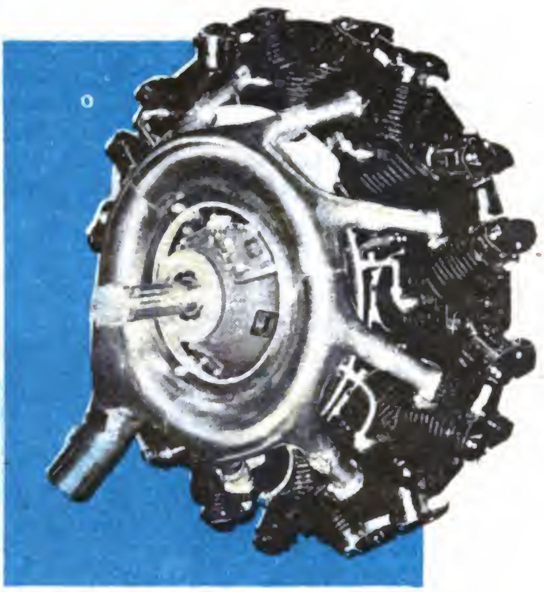
The Whirlwind in its early form was but a few steps removed from the early radials of Charles Lawrance. They were unsupercharged, and developed in the neighborhood of 200 horsepower at the most.

Used in Private Planes

As the years went on, and Wright Aeronautical developed its Cyclone series of engines in the higher horsepower brackets, Whirlwind development went on unobtrusively. In the middle 30's Whirlwinds were used largely for the powering of comparatively small private airplanes — the so-called "commuter" type plane which is expected to come again into vogue after the war.

With the steady improvement in the Whirlwind, Wright Aeronautical engineers succeeded—as they did with Cyclone engines — in keeping the increasingly powerful engines within space restrictions. Thus, the 7-cylinder Whirlwind of 235 horsepower has a diameter of 45 inches; the 450 horsepower Whirlwind, which came along in time for use in the tanks, also has a diameter of 45 inches.

In early experiments with tank installations, a seven-cylinder Whirlwind — the R-760 — was installed in a tank back in 1934. Cooling problems and drive trans-



Whirlwind R-975

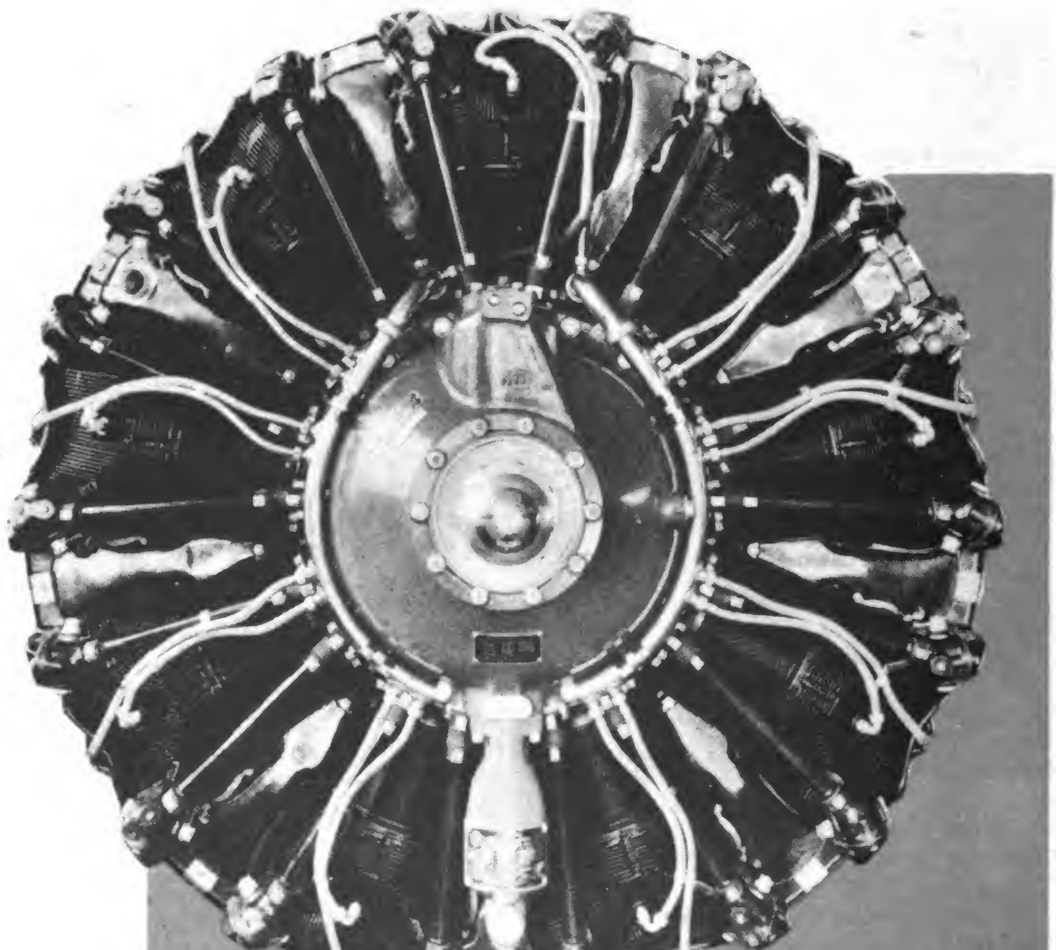
mission problems were overcome only after much development work, but eventually the engine did qualify in a T-2 tank. This was the ice breaker. In later development the more powerful Whirlwind 9, the R-975, was made ready for M-3 and M-4 tanks and drove them across proving grounds and battlefronts at speeds thought impossible for the monsters.

To put a radial air-cooled engine into a tank, it was necessary to provide for a special induction system to insure an adequate air supply. Because the engine was mounted in a manner that made cooling by the vehicle's motion impossible, the engine has to do its own cooling; this by way of a many-bladed rotary fan. Other special provisions included vents for gasoline tanks to prevent fuel from becoming too hot in desert heat, and filters to keep the sand out.

No. 27 — The Cyclone 9

Looking at the engine now as a whole, one can take the Cyclone 9 as representative of the full line of Cyclone and Whirlwind radial engines. The basic principles governing the operation of Whirlwinds and two-row Cyclones apply alike to the Cyclone 9.

In the development of the Cyclone 9, there have been three principal types: the "F" Cyclone, which powered airlines of the middle thirties; the G100, and the G200. The G100 series of 1100 horsepower Cyclone 9's was developed during the thirties, the era when the airlines were emerging from the status of spectacular but erratic operation to the modern airline's routine but dependable performance. The G100 Cyclone—still in use in many aircraft throughout the world — made its mark in more ways than one; it helped to prove that long range flight was practicable and economical; it provided technicians with sheaves of experience data that



Cyclone 9

helped to advance the further development of aircraft engines; it made its share of distance flights, achieved a reputation for timetable dependability for the aircraft it powered.

Two Cyclone 9's of the G100 series powered the Lockheed Transport in which Howard Hughes flew around the world in three days and 19 hours, a flight which was considered newsworthy at the time, not only for its speed but because Hughes' plane flew in large measure over a route new to air travel, and arrived at destinations when it was scheduled to arrive — a novelty then, commonplace now.

The G100 engine was a link in the generation-long chain of Wright engine development. It had grown out of a Cyclone 9 of 525 horsepower developed originally back in 1927, the year Lindbergh flew the Atlantic in a Whirlwind-powered plane.

G100 was Prototype

The G100, in its turn, led to development on the current Cyclone 9, the G200. Still a nine-cylinder engine, still the same power plant in principle, the G200 today is more powerful than the husky G100, developing 1200 horsepower for takeoff, turning out the power which flies such warplanes as Flying Fortresses and Douglas SBD Dive Bombers. Adaptable, the G200 may be equipped with a two-speed supercharger, torque meter, and various accessory drive combinations. It is available with either .666 or .5625 reduction gear ratios. In an earlier chapter, the principle of gear reduction (to which these ratios pertain) was explained.

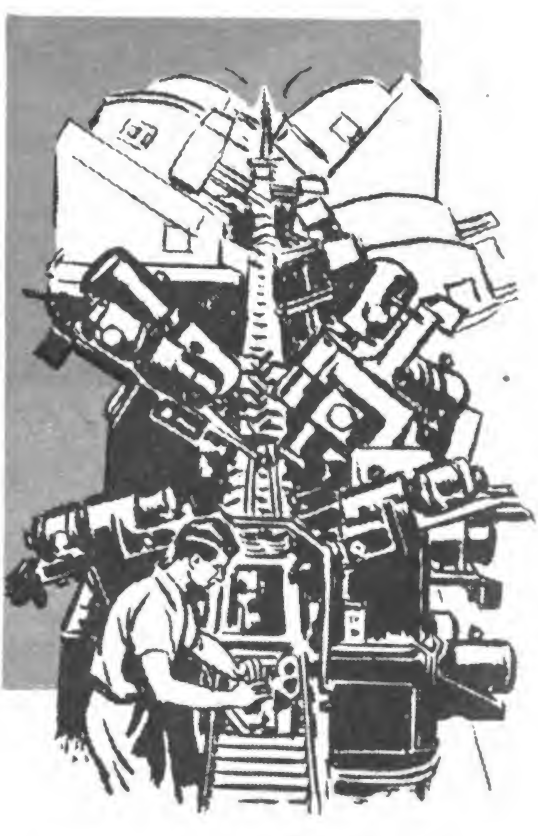
While all of the features of the Cyclone 9 (as represented by the G200) cannot be described in one story, some of the highlights will help to show what goes into the making of the engine:

The engine's cylinder has a cooling fin area of 24.4 square feet, the fins measuring 2¼ inches in depth at the top of the cylinder. Cylinder heads are of cast aluminum alloy; cylinder barrels of high quality steel, precision-finished and processed for maximuum strength.

Master rods for Cyclone 9's are of the end-sealed type, a feature introduced with later models of the G100 which assures constant adequate lubrication to the all-important master rod bearings.

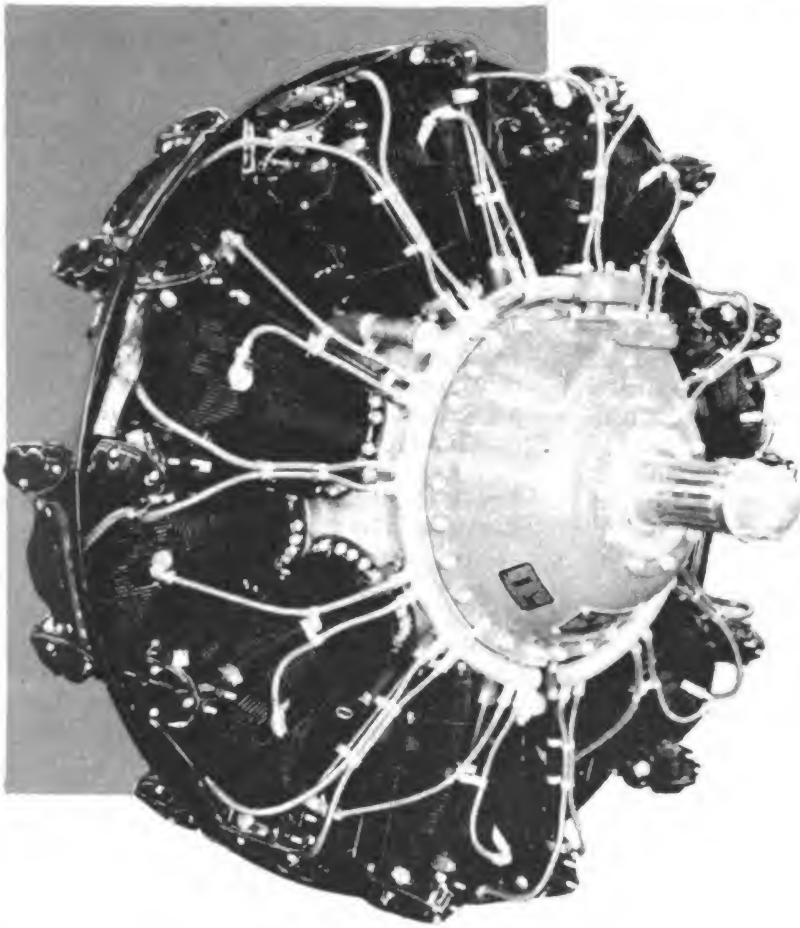
Typical of the continual improvement made in the Cyclone 9's is the attention given to the crankcase. The new steel crankcase of the G200, while necessarily strengthened to accommodate the increased power of the engine, is of such advanced design that it weighs less than the corresponding aluminum section of the earlier G Series Cyclones. The new crankcase incorporates a completely new scavenging system, and eliminates all studs and external bolts.

The G200 Cyclone 9 engine, like engines in the upper horsepower brackets, has its dynamic damping feature. In the G200, the crankshaft counterweights are both of the dynamic damper type; free-swinging pendulums mounted, as explained in the chapter on the dynamic damper, by the use of pins in the crankcheek extending through oversize holes in the counterweights.



Wright Designed Multi-purpose Machines

No. 28 — The Cyclone 14



2600-B model of Cyclone 14

Conceded by all aviation authorities to be the ice-breaker among long-range, high-horsepower engines, the Cyclone 14 came upon the air transport scene at just the right time. Such globe-girdling airlines as Pan American had built themselves up to the point at which a more powerful engine was necessary for the next milestone: longer range planes carrying heavier payloads greater distances — with endurance and engine reliability as faithful as that which had become characteristic of the Cyclone 9's in Douglas DC-3 airliners.

The Cyclone 14, a two-row radial air-cooled engine, was like the Cyclone 9, the product of a long series of development projects. First came development work on two-row Wright engines; then there was a small 14 cylinder engine of 1510 cubic inches displacement; then the R-1670, with a 1670 cubic inch displacement.

1670 Pioneered

Besides being of the two-row type this 1670 model pioneered with many features which were then innovations, now standard Wright engine features; such things as down draft carburetion, supercharger impellers running on plain bearings, spur gear reduction gears of the planetary type, built-up two-throw crankshafts, high-finned cylinder heads, and spark plug cooling fins.

Coming along on the heels of the 1670, the Cyclone 14, as it is known today, appeared first as the 2600-A engine. Developing 1500 horsepower at takeoff the 2600-A model of the Cyclone 14 was almost immediately put into use in Pan American's Boeing

Clippers. Its use was extended to other planes.

As Wright Aeronautical engineers continued their development work with the two-row radial, the Cyclone 14 was progressively improved and more and more power was obtained as design changes enabled the engine to carry greater loads. The forged aluminum crankcase in the 2600-A model gave way to a forged steel crankcase in the 2600-B engine which was made of such rugged metal that the steel case actually weighed less than the early aluminum case. Later models of the Cyclone 14 currently in production have an output of 1600 horsepower and 1700 horsepower.

World War II finds the Cyclone 14 contributing its power and ruggedness to propulsion of such planes as the Martin Mariner, Curtiss Helldivers, Grumman Avengers, and North American Mitchells.

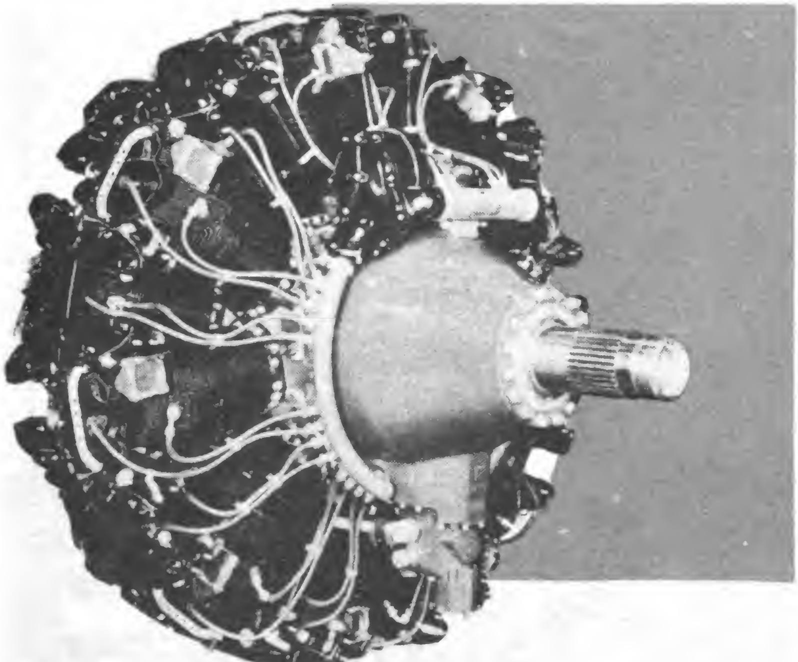
No. 29 — The "3350" Cyclone 18

Back in 1927 Wright Aeronautical gave the aviation industry an air-cooled radial engine that developed 525 horsepower, yet presented to the airstream a frontal area but 55 inches in diameter. That engine of more than 15 years ago was a Cyclone, the original 9 cylinder version, one of the pioneers in powering early airlines and a development held at the time a major improvement in making possible long range air line operations.

Today, Wright Aeronautical is building another new engine: the "3350" Cyclone 18. Like the engine of more than 15 years ago, this new power plant has a frontal area exactly 55 inches in diameter. With its improved cowling and baffling system this new power plant actually presents less resistance to the airstream than that early Cyclone 9.

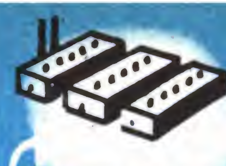
But instead of 525 horsepower, this 1944 power plant has an output of 2,200 horsepower, more than four times as much.

The "3350" Cyclone 18, so-called because it has a cylinder displacement of 3350 cubic inches, is longer than the Cyclone 9 with which it contrasts, but no heavier in proportion to horsepower. The new engine has a characteristically long nose section to house the reduction gear train employed to gear down the crankshaft speed to a speed acceptable to the propeller. Similarly, at the rear of the engine a large housing encloses a supercharger with induction potentialities greater than any supercharger previously built upon a Wright engine.



"3350" Cyclone 18 Has Long Nose Section

RAW MATERIALS — From 18 states and South America come the 36 different kinds of material that compose the engine; scores of other materials help out in the manufacturing process. For each completed engine, leaving: 9,000 lbs. of raw materials, entering.



SUBCONTRACTORS — At war's peak, more than 800 subcontractors helped. From 26 states, they provided large portions of major parts like crankshafts, accessories such as carburetors and magnetos; and little things—from washers to spark plugs.

FOUNDRY — Mechanized, conveyorized, today's foundries make magnesium and aluminum castings on a "line production" basis, rough-finish and clean them, and send them on to be machined. Wright Aeronautical foundries process the lightest metals: aluminum, magnesium.

TESTING: LAB ANALYSIS — Nine general types of tests are made on raw metal for foundries; also tested are bar stock and forgings headed directly for machining. Tests include chemical analyses; microscopic X-ray and visual inspection; and physical tests by tensile-testing torture machines.

MACHINING—Thousands of machine tools fill the shops, up and down miles of aisles. Their job is to cut, drill, shape and smooth; tens of thousands of operations on each of the 8,000 and more parts of each engine. Machining delivers completed parts, large and small.

MACHINING ASSEMBLY—Here the job is a combination of machining and assembly, a matter of completing 185 machining assembly units from many more components. These units in turn become components of the engine shaping up through assembly.

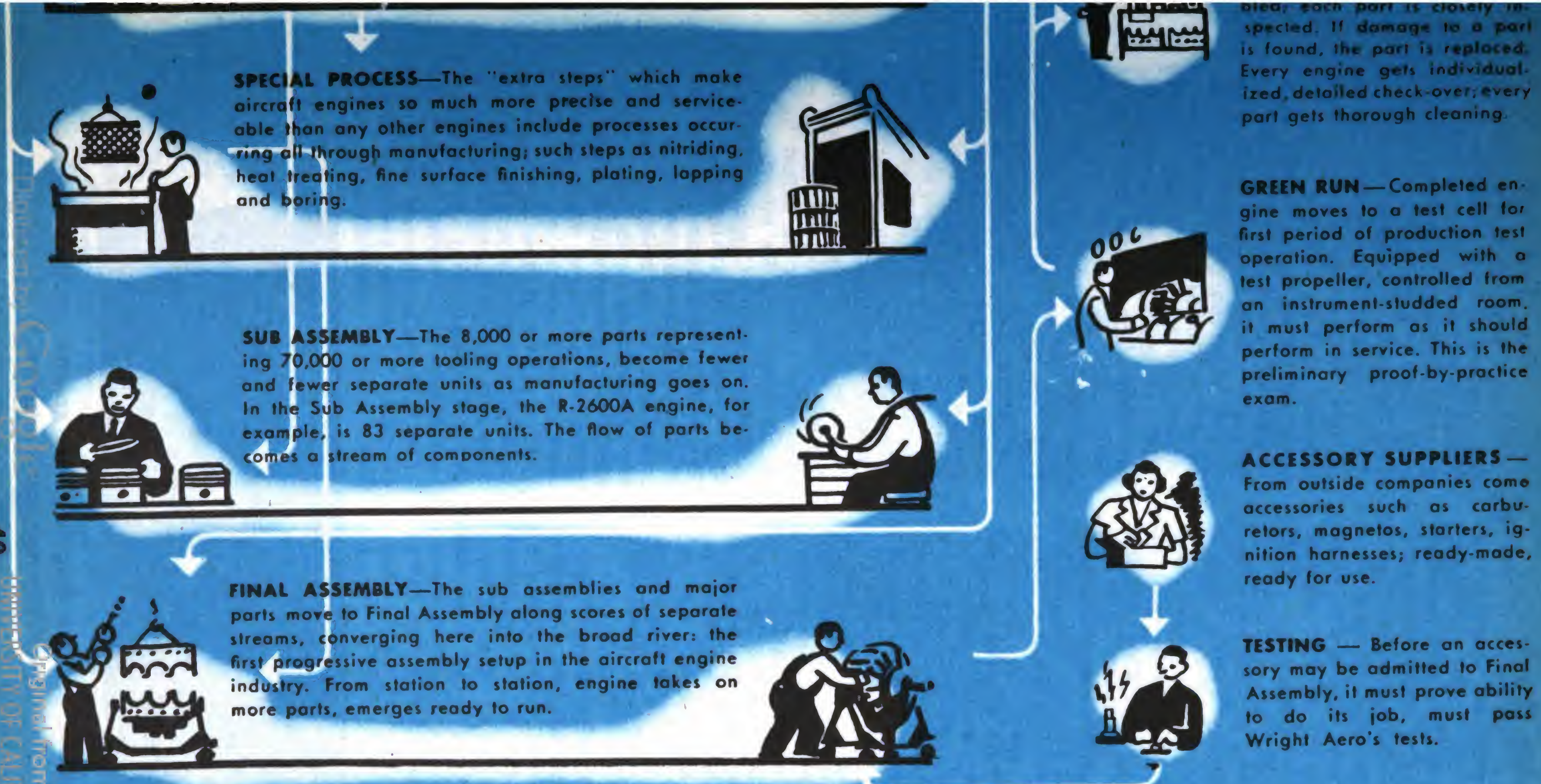
PACKING AND SHIPPING—Mounted in a steel cradle, sheathed in an air tight Pliofilm container provided with a chemical moisture signal, the engine enters its heavy wooden box and starts on its way.

WASHING AND INSPECTING—To rid engine of dirt and make it corrosion-proof for shipping, engine goes through "engine laundry," gets thorough checkover—the last of more than 55,000 inspection operations in its manufacture.

FINAL TEST RUN—Now come more hours of operation, more close control as engine runs at cruising, takeoff, idling — all the conditions likely in service flight. This is the final exam: this gives engine testers chance to say engine *will* perform at all speeds — because it *has* performed.

REASSEMBLY—The engine is put together all over again. If Green Run, Disassembly and Inspection give it okay, it goes on for Final Run; if there is a major part replacement, an extra "penalty" run with subsequent disassembly and inspection must occur before Final Run.

DISASSEMBLY AND INSPECTION—Green Run over, the



HOW AN AIRCRAFT ENGINE IS BUILT

Here is a "flow chart" which depicts the principal steps in the manufacture of an aircraft engine. Showing how a **Wright Cyclone** is made, it gives some idea of the infinite precision, the engineering and manufacturing skill, and the "extra steps" involved in the production process.

Uses Light Materials

Other construction features include aluminum alloy cylinder heads and nitralloy steel cylinder barrels, use of a steel crankcase which permits taking more power from the engine than possible with an aluminum case, and use of light weight magnesium in nose section and supercharger housings — light weight materials which help to bring the Cyclone 18's weight down to just fractionally over a pound per horsepower.

Putting the power to pull a freight train into one engine created new propeller gearing problems, for simply elongating the propellers to absorb the 2,200 horsepower would cause the blade tips — more than ten feet out from the shaft—to revolve at such a rate that they would exceed the speed of sound and get into that little known realm of movement where shock waves are built up and efficiency seriously impaired. The propeller speed had to be slowed down and blades then widened out to absorb the power. Wright engineers, in solving this problem, designed for the Cyclone 18 a reduction gear system with what is probably the lowest ratio ever used on any aircraft engine. Thus, at an average cruising speed the propeller turns at only 600 revolutions per minute.

However, to the world both friendly and enemy, the construction details of this new engine are not so important as the question of what it will do, what it will mean to our air power. And the answer is that it will carry more destructive weight aloft, and carry it farther, than has ever been carried before.

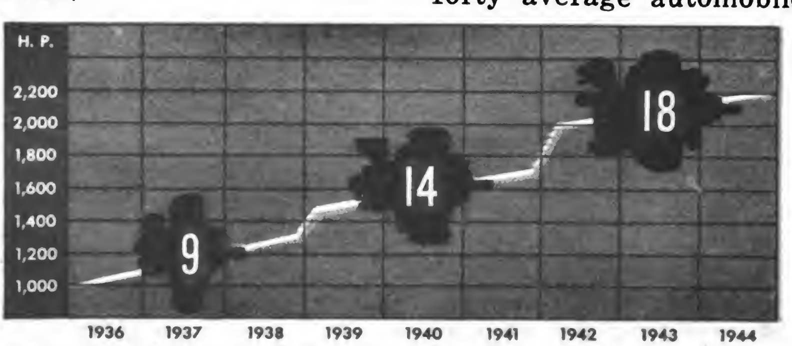
Can Climb High

Wright engineers, in building the Cyclone 18 to produce 2,200 horsepower, took this trend into consideration and designed the engine for a high altitude rating. The Cyclone 18's displacement of 3,350 cubic inches gives it the volume to provide air for combustion at high altitude. To this basic construction of 3,350 cubic inches of displacement, the engineers added a two-speed gear-driven supercharger with a wide-diameter impeller, capable of speeds up to more than 25,000 RPM, to maintain pressure in the cylinders. The engine may also be used with a turbo-driven supercharger, where this type of compression is needed for power at high altitudes.

Cyclone 18's — four in each aircraft — today power the giant Boeing B-29 "superfortresses," the world's largest, fastest and longest-range bomber. The same engines power the huge, shark-shaped Lockheed Constellations. The first of these big planes — heralding postwar transport possibilities — flew cross country on a test flight in six hours and 58 minutes.

More recently, Cyclone 18's in a new commercial transport model, will power the Curtiss CW 20 Commando. Tried and proven in rugged flight in its military version, the Commando with its Curtiss electric propellers will be ready for peacetime air travel when the war ends.

Illustrative of the super-power built into modern aircraft engines, note that engineers have figured a single Cyclone for a twin-engined Commando is powerful enough to lift a half-ton elevator at the speed of sound — more powerful than forty average automobiles!



The "Curve" of Aircraft Engine power growth, as represented by Cyclone maximum outputs.

Vibration must be reckoned with in aircraft engines such as Cyclones—reckoned with in the design of the power plant before it ever gets into operation. Kept under control by correct design and arrangement of the engine's parts, vibration can be absorbed.

Features of Cyclones such as dynamic damping make possible vibration control.

The effect of vibration may be illustrated by a simple analogy. Think of a man riding horseback. Particularly when the horse is trotting, his saddle is moving up and down briskly. The beginner finds the sudden impacts of the saddle very tiring; those repeated impacts are like the numerous separate shocks which go to make up the condition of vibration. When the horseman becomes more experienced, however, he can "dampen out" the blows of the saddle by posting—by moving his body in time with the movements of the horse. He eliminates the shocks of trotting by absorbing them.

Power not Continuous

In an engine such as a Cyclone the power behind these separate impulses is greater in but one cylinder than the force behind the jogging of many horses. As with the horse, the pressure produced is not the continuous, uninterrupted pressure that a hydraulic pump, for example, would give. In the four-stroke cycle by which Cyclones operate, the power — the actual drive imparted to the piston and passed along to turn the crankshaft—is produced in but one in every four strokes. The other three strokes simply make it possible for the power stroke to occur.

Each power stroke is a separate impulse which results in a turning force on the crankshaft which varies as the succesive impulses are applied. This variation constitutes an "exciting force" which causes what is known as "torsional vibration." Considering the intensity of that vibration, rising as it does from the output of some 133 horsepower per cylinder, it is a factor which must be kept from getting out of hand.

The dynamic damper serves this purpose. A Cyclone feature, the dynamic damper is built into the counterweight, operating at right angles to the axis of the crankshaft. For correct internal balance, the Cyclone must have a counterweight anyway, so the dynamic damper actually adds no weight to the power plant—it merely makes the counterweight serve the dual purpose of balancing and vibration-damping.

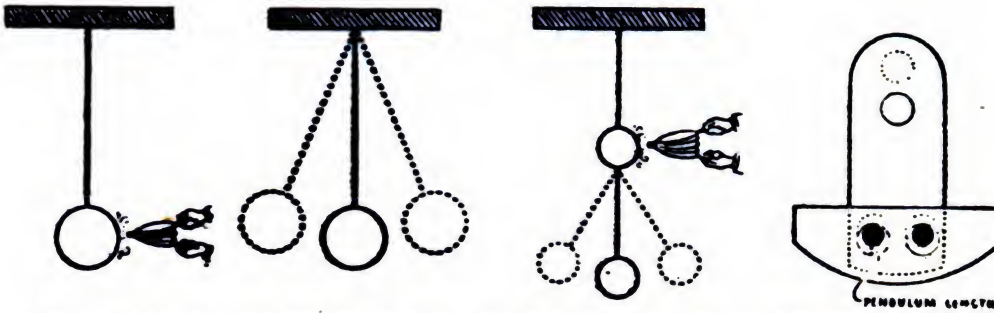
While Wright Aeronautical owns the patent rights to the dynamic damper, this feature has been made available for use in other types of aircraft engines.

Works Like Pendulum

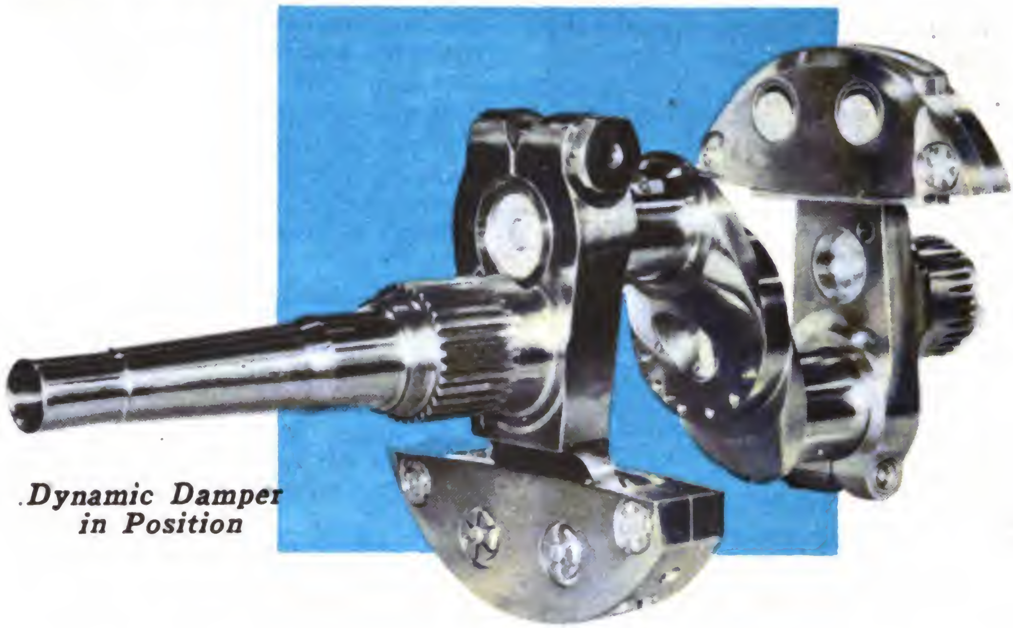
To see how the dynamic damper works, look at the drawings of the pendulum in this chapter. If a simple pendulum were given a series of regular impulses, one following another at identical time intervals, the pendulum (as in the diagram) would commence swinging, or vibrating — moving back and forth.

Suspend a second pendulum of the proper size from the first, as in the succeeding sketch in the series of drawings, and the second pendulum will absorb the impulses and swing itself, leaving the first stationary.

So it is with dynamic damping. The dynamic damper is a short pendulum hung on the crankshaft and tuned to the frequency of the power impulses to absorb torsional vibration in the same manner. The dynamic damper is simple in construction, consisting in essence of rocker-shaped weights which are attached to the crankshaft's crank-cheek by two pins. But the pins fit into holes in the dynamic damper counterweight which are oversize. The difference between the diameters of the pins and the holes makes possible the motion which is equivalent to that of the second pendulum.



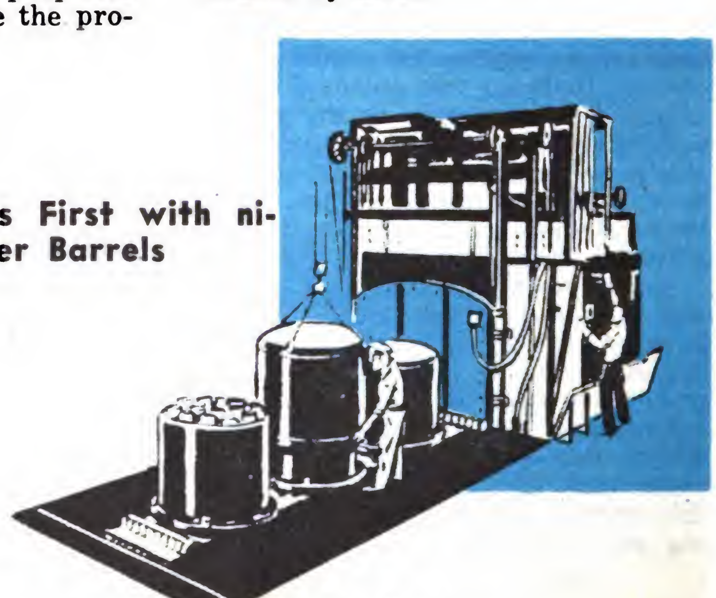
Drawings at top illustrate principle of dynamic damper. Photo of crankshaft, below shows position of dynamic damper counterweight. This engine feature is patented by Wright Aeronautical, licensed under F.M.M.B. Salomon patents.



Dynamic Damper in Position

The dynamic damper is effective in controlling "torsional vibration" which would be destructive to the crankshaft, the propeller and the gears which drive the propeller and the supercharger. It does not control the shaking forces nor the vibration in other forms caused by them.

Wright was First with nitrided Cylinder Barrels

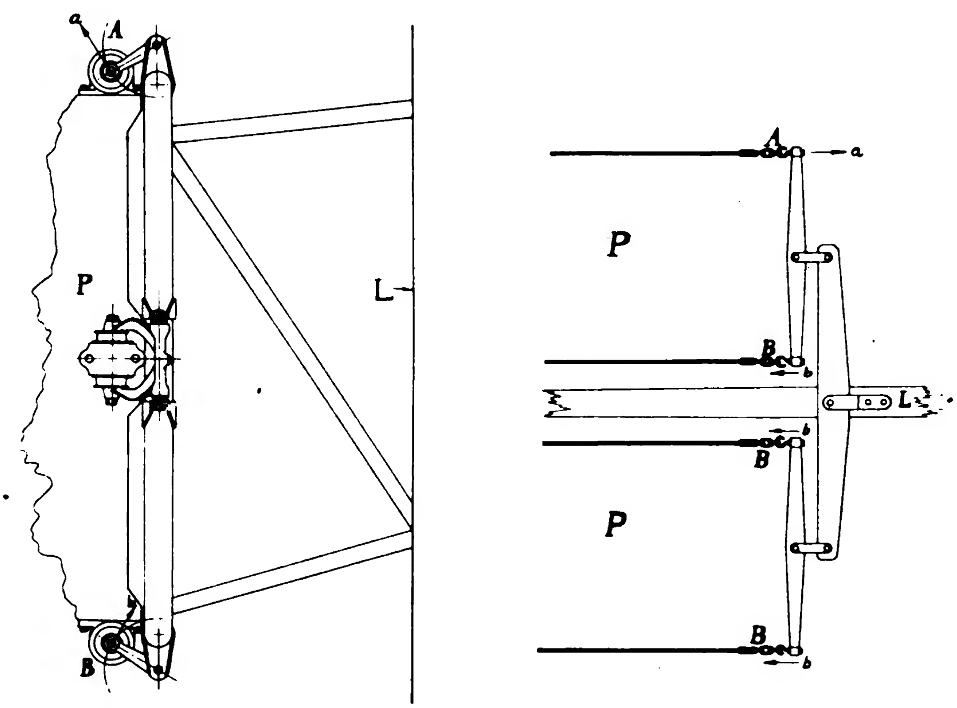


No. 31 — Dynamic Suspension

Having built an engine of — say — 2,200 horsepower, an aircraft engine manufacturer such as Wright Aeronautical finds itself with a tremendously powerful bundle of machinery on its hands. In attaching that source of vast power to an aircraft, the manufacturer must — and does — take a few homely pointers from the horseman. The husky horse is not harnessed to the wagon with a few strands of rope and a stove bolt; it is made part of the team of horse and wagon through specially constructed, movable, flexible apparatus such as leather strapping, horse collar, and the "whiffletree."

Without the carefully designed linking apparatus, any healthy horse could buck himself out of place or damage the wagon in no time.

The Cyclone 18 (or any other aircraft engine) presents a similar problem. The aircraft radial turns over at upwards of 1900 or more revolutions a minute; generated in each cylinder are 15 tons of pressure, to become power; the propulsive force thus generated turns a propeller through a diameter of as much as 16 feet or so. By careful design, Wright Aeronautical engineers control much of the vibration. High precision, exact fits, keep the vibrating down; the "dynamic damper" mounted on the crankshaft (as indicated in an earlier chapter) absorbs a special portion of the vibrations. But 2,200 horsepower — or 500, or 1,000 — still creates considerable vibration that the engine cannot swallow.



Here are identical solutions of two different problems. Note that in either whiffle tree (r) or engine mount (1), a point of attachment "A" can move in either direction as "a", and this movement can be compensated by an opposite movement "b" of point or points "B"; thus permitting the relationship of the load "L" and the power plant "P" to remain unchanged.

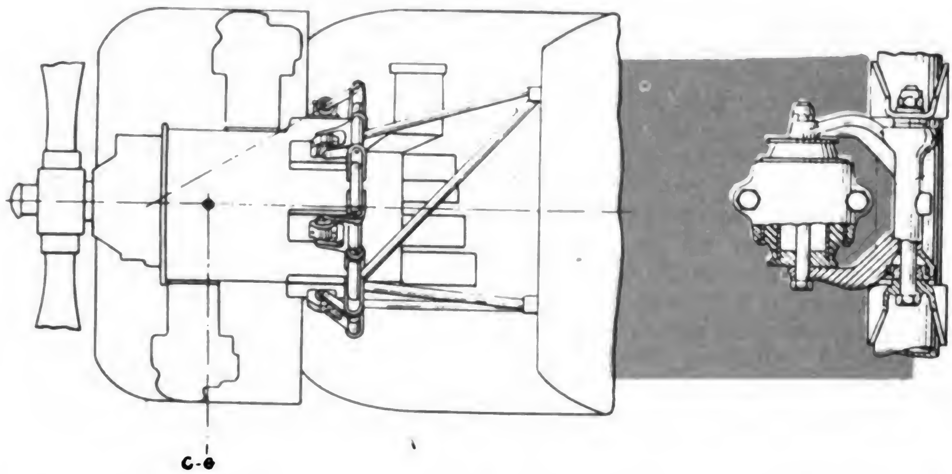


Diagram of Dynamic suspension, showing relative position of center of gravity (c.g.) and the intersection of axis of engine with axis of suspension links.

The engine on an aircraft tends to vibrate on three axes. Experience has shown that best results—for both engine and aircraft — are obtained by giving the engine freedom to exhaust these tendencies to vibrate without transmitting the vibration-exciting forces to the plane structure.

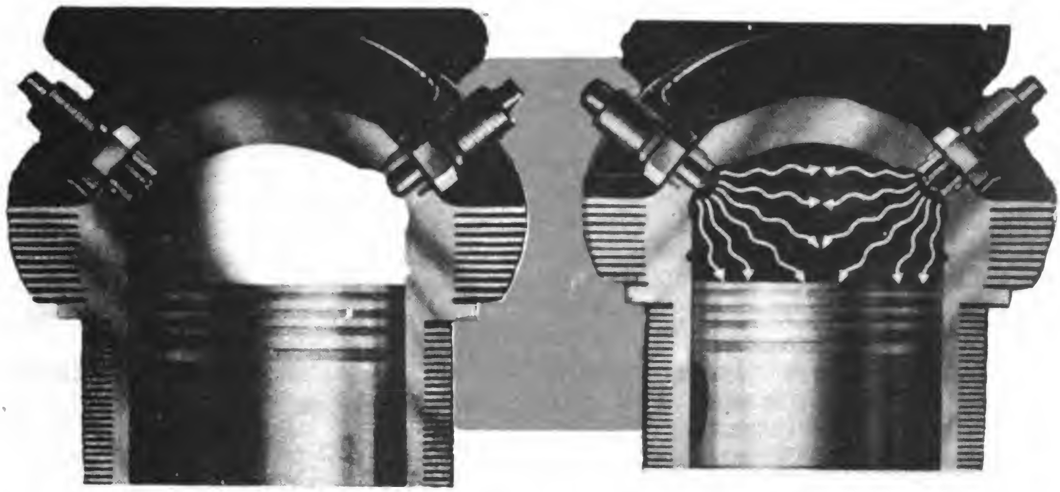
Wright Aeronautical's outstanding contributing to this problem is "dynamic suspension." Dynamic suspension has been recognized as so vast an improvement over the old type "flexible mounts" that high horsepower development would be seriously handicapped without it.

The flexible mounts permitted the aircraft engines they supported to discharge their vibrating forces in all directions, but they also allowed the engines to "droop." This was found to be bad, since the drooping opened the way to unwanted "pitching" and "yawing" characteristics. Vibration tending in one direction, through the flexible mount was too often translated into vibration in other directions.

Dynamic suspension — like the horse and wagon linking device of horse collar and whiffletree — is essentially simple. Dynamic suspension prevents the undesirable "droop" by giving the equivalent support in front of, as well as behind, the center of gravity. When this is done, the tendency to droop simply disappears, and does not reverse itself. Like the whiffletree, illustrated here, the links of dynamic suspension mounts permit relative motion. Like the whiffletree, too, they hold the proper relationship of the center of gravity to the whole load, at all times.

Through dynamic suspension, it has been possible to mount Cyclones on airliners in a manner that blanks out most of the vibration before it gets to passengers.

Wright Powered First Air visit to Tokyo in Peace (1928) and First in War 1942)



Normal combustion (left) is characterized by a flame which starts slowly at the points of the spark plug, spreading rapidly through the rest of the fuel-air mixture. With multiple ignition (right) the time required for burning the fuel-air mixture is beneficially reduced, since the two flame fronts, traveling in opposite directions, require less time to pass through the unburned mixture. (Illustrations from the Wright Aero film "Cyclone Combustion".)

Rapid combustion in the cylinder of an internal combustion engine greatly increases the pressure acting on the piston. This increase in pressure causes the piston to move, permitting the gas to expand and, through the connecting rod linkage, rotating the crankshaft that is responsible for turning the propeller. It's like the fabled "this is the dog that chased the cat that chased the mouse that lived in the house that Jack built."

At the beginning of the series of events that result in the actual power, the gasoline which enters the cylinder on the intake stroke as part of the fuel-air mixture must be metered by the carburetor in the correct proportion to the weight of air in the mixture.

Rapid combustion will not occur if gasoline is introduced in its liquid state. In air, liquid gasoline will burn with an intense flame—but won't burn in that rapid manner that constitutes exploding.

Having vaporized the fuel and mixed it with air, the fuel-air mixture is next compressed by the piston during the compression stroke to the point in the cycle at which ignition takes place.

Compression Does It

Theoretically, it would be possible to ignite the mixture by flint and steel, mechanically. In a Diesel engine, ignition is brought about by compression of the mixture to the point at which the temperature thus produced is equal to the fuel's kindling temperature.

In the four-stroke cycle gasoline engine, such as a Cyclone or Whirlwind, electricity is the igniting medium. The ignition system with its spark plugs, magneto, and current-carrying ignition "harness," creates and doles out the high-intensity electrical sparks of ignition.

Electricity is the ideal means of starting combustion. Traveling through wires at 186,000 miles a second, it's always on hand at the spark plugs when it's wanted, no matter how fast the engine is operated. Getting the current up to the spark plug on time has never been a problem in building ignition systems.

Calls For Plugs

But making the electricity jump through space between the two terminal points of a spark plug calls for special arrangements in the construction of the ignition system.

Just as no lightning will occur unless an electrical charge in the sky is built up to sufficient intensity to jump earthward, so no combustion-starting spark will occur unless the electrical charge reaching the spark plugs is of sufficient intensity to jump the spark plug gap.

The "gap" is a carefully worked-out distance; varying in different types of internal combustion engines, it is fixed by manufacturer's specifications. For each Cyclone and Whirlwind model, Wright Aeronautical indicates for engine users what fraction of an inch distance the spark plug gap should be.

To jump the gap of the spark plug, the electrical current must be of high voltage. High voltage enables the current to overcome obstacles just as high pressure enables a stream of water to rise to heights or break through resistance.

For the current creating the spark of ignition, there are some very real obstacles. The gap itself is one. Another is the pressure within the cylinder; at the moment of ignition, the pressure of the uncombusted gas-air mixture is at maximum because the piston has risen to the top of its compression stroke.

Moisture within the cylinder may condense on the spark plug, and lubricating oil may form a film on the electrodes of the spark plug, creating additional obstacles for the spark.

All of these technical hurdles are reasons why spark plugs must be precision instruments and magnetos must supply high voltage consistently.

No. 33 — Normal Combustion

To consider some more advanced facts about power production, think of the four-stroke cycle for a moment. Remember that power in a Cyclone or Whirlwind is produced by the expansion of the rapidly-burning gas-air mixture. Basically, power is the net result of what occurs in all of the four strokes—intake, to introduce the

In detonation, the last part of the charge virtually explodes simultaneously, creating volcanic local temperatures and pressures which impinge directly on the piston and cylinder walls.

combustible mixture into the cylinders; compression, to confine the mixture into as small a space as possible for greater efficiency on the power-producing stroke; power, to ignite the combustible charge and produce power; and exhaust, to scavenge the burned gases out of the cylinders, making way for the next complete cycle.

But, in an aircraft engine which runs at high speed, varying temperature, and high power, it is not sufficient to permit these four strokes to occur catch-as-catch-can. Unless favorable conditions are established, the all-important rapid combustion of the gas-air combination will occur too late, too soon, or unevenly. Result will be at the least, loss of power; at the worst, harm to the engine through "knocking." Knocking is a characteristic of the much-to-be avoided "detonation."

"Ping" Is Familiar

The audible "knock" or "ping" of detonation is a familiar sound in automobile engines using fuel of low anti-knock value. Auto engines with high-compression cylinder heads exhibit this tendency to knock especially when accelerated too quickly or when climbing steep hills.

It is important to note that it is the fuel — not the engine — which detonates.

In aircraft engines, detonation does not announce its presence by an audible "knock" or "ping." Seldom heard by pilots above other engine and propeller sounds it must be detected by puffs of black smoke and a bluish-white flame where the exhaust is visible. Also noted will be a sharp rise registered by the cylinder-head temperature gauge.

In normal combustion, with one of a Cyclone's two magnetos cut out, the flame "front" in combustion travels across the combustion chamber at a fairly constant velocity of about 100 feet a second, slowing somewhat as it approaches the far wall of the cylinder. In detonation, combustion is quite normal up to the point where detonation starts. Thereafter, the nature of combustion becomes entirely different. The so-called detonation wave is started, and the last part of the charge virtually explodes simultaneously. This explosion creates extremely high temperatures and pressures within the combustion chamber which impose their stresses directly upon pistons and cylinder walls.

Developes Pressure-Wave

Even during moderately heavy detonation, the pressure-waves generated are so intense that they can cause the walls of the combustion chamber to spring and vibrate. This vibration is heard as the characteristic "ping" of the audible knock.

In operating an automobile engine at the comparatively low speeds and short distances of driving-to-work, motorists are well advised to make certain that detonation is avoided; how much more important it is to avoid detonation in Cyclones, operating as they do in high-speed, long range aircraft. One of many measures which help to reduce the possibility of detonation in Cyclones is multiple ignition. The average auto engine has but one spark plug per cylinder; the Cyclone has two — thus, "multiple ignition." Multiple ignition radically reduces the engine's reactions to the conditions which produce detonation. With multiple ignition, the time required for burning the fuel-air mixture is beneficially reduced, since two flame fronts of combustion, traveling toward one another from the two spark plugs, require less time to pass through the unburned mixture than one flame front.

In less than three hours, a Cyclone 18 requires for combustion more air than could be contained in a K-type blimp.

No. 34 — Gasoline

Gasoline is the fuel burned in an engine cylinder. It develops power by rapidly heating a compressed charge of air. To operate efficiently it must meet rigid specifications adapted to the mechanical requirements of the engine using the fuel. Automobile and aviation engines differ enough in mechanical and operating charcteristics to require two distinct gasolines.

"Octane rating" is the most important criterion of performance. Octane rating is a measure of the knocking of the gasoline, compared with the extremely knock-free substance, iso-octane, arbitrarily assigned a value of 100 on the knock-rating scale. The air-gasoline charge in a cylinder is compressed before being ignited by the spark, the extent to which it is compressed depending upon the compression ratios of the engine.

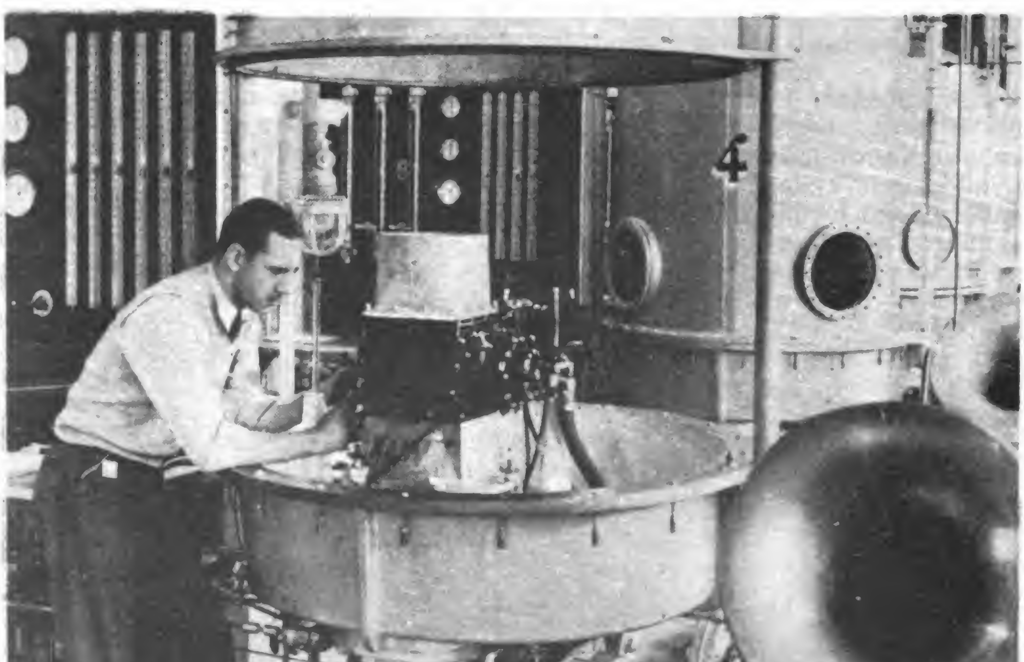
The more highly the air-fuel mixture is compressed, the greater the power developed, providing knocking does not occur. Knocking is overcome by adding to a gasoline tetraethyl lead and certain special petroleum derivatives.

Although the explanation of the cause of knocking is not known, ways are known of segregating and concentrating compounds of low knocking tendencies in finished gasoline.

Must Meet Demands

The antiknock quality of the fuel must meet the demands of the engine. Thus, aviation engines have higher compression ratios and require higher octane rating fuel than automobile engines. On the other hand, low compression engines are not benefited by high octane fuel.

For instance, there would be no advantage in using aviation gasoline in present-day automobile engines. Gasolines are supplied at various octane rating levels, and for proper engine performance the gasoline corresponding to the engine requirements must be selected. Aviation engines built for 100 octane aviation gasoline will develop their full high power without knocking on 100 octane aviation



In this carburetor test laboratory at Wright Aeronautical, technicians make certain that each carburetor, for each engine manufactured, will perform its job of serving gasoline-air mixture to combustion chambers. Equipment shown here simulates flight pressure conditions.

gasoline. However, on lower octane rating gasoline, lack of power and a knock destructive to the engine will result.

The other most significant property from the standpoint of performance is volatility: volatility indicates the readiness with which a gasoline will evaporate.

Operate on Liquid Fuel

Volatility is controlled by the temperature range over which gasoline boils. Fuel systems of both automobile and aviation engines are designed to operate on liquid fuel. Too volatile gasoline will partly vaporize in the lines leading to the carburetor and impair the efficiency of the fuel pump or suction. Severe vaporization will completely stop an engine through "vapor lock." In the summertime the high temperature under the hood of an automobile will tend to vaporize the gasoline. Also, at **high altitudes** the low atmospheric pressure will tend to vaporize the gasoline in an airplane. Because of the different conditions in automobile and aviation service, volatility characteristics of gasolines for the two must be different.

High volatility facilitates starting of cold automobile engines. Consequently, volatility of motor gasoline is set as high as is possible without risking vapor lock, and is higher in winter than in summer grade gasoline.

Even Distribution Needed

Efficient utilization calls for uniform distribution of gasoline among all cylinders of a multicylinder engine such as a Cyclone. The temperature range over which the higher boiling portions of gasoline distill are indicative of distribution characteristics. Too high a boiling range will cause condensation of liquid gasoline along the manifold and the starving of some cylinders.

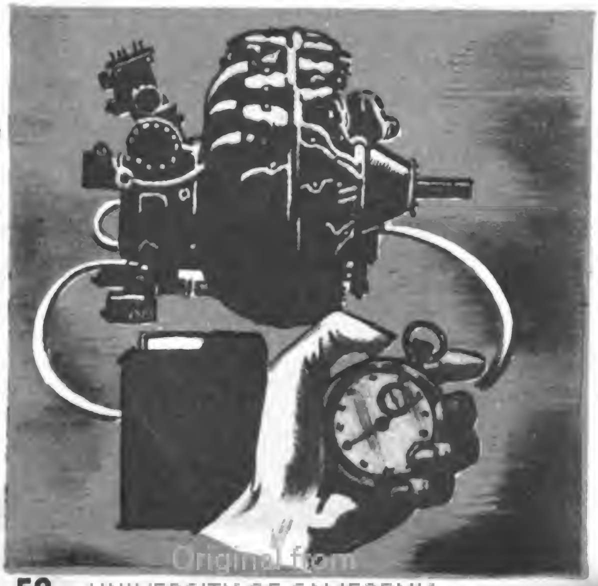
Because of the relatively simple manifolding of an automobile engine, motor gasoline can have a higher boiling temperature than aviation gasoline. The final boiling temperature of motor gasoline is higher than that of aviation gasoline.

Gasolines must also have purity standards. They must not contain more than a specified amount of sulfur because sulfur compounds may be corrosive or may form corrosive compounds; they must be low in gum because gum may stick valves or rings; and they must be stable so as not to deteriorate in storage.

Gasoline specifications must of necessity be changeable. Gasoline development must go hand in hand with engine development so that the highest developments in the two can complement each other. Gasolines must perform under extreme atmospheric temperatures and pressures. Specifications, therefore, must represent compromises that will insure quality over wide ranges of operating conditions.

This installment of Enginology was prepared by Standard Oil Co., (N. J.)

A Cyclone 18's oil-pumping system is capable of circulating at the rate of more than 43 gallons a minute (both for engine and by-pass).



No. 35 — The Weight Factor

From the very beginning of powered flight, one of the primary considerations in the design and construction of an aircraft engine has been weight. To the layman, the extreme measures taken by this industry to knock off every possible pound — then every possible ounce —may seem far-fetched. But literally, every ounce of weight safely removed from an engine-in-design is an additional ounce of payload which can be taken aboard an aircraft many times during the lifetime of both engine and airplane.

to 150,000 revenue-pound-miles. In wartime, these savings, multiplied by the total number of pounds of savings in engine weight made possible through the years, and multiplied by the number of miles flown across far-flung battle-fronts, represent a vast quantity of war material which can get into the fight quickly.

In peacetime, the saving in weight is directly related to the question whether or not an airline can operate profitably. Compelled to leave part of its payload behind

Toward the Super-Transport: Aircraft Weight Continues to Rise

The Wright brothers' plane weighed 600 pounds.

The Cyclone-powered Mars weighs 140,000 pounds.

The mathematics of this situation is interesting.

Suppose an airplane flies 150,000 miles a year. Suppose, too, that it is loaded to the limit for all of those 150,000 miles. Since the weight of the engine is a factor in the total permissible weight of the airplane — and since that total weight also includes the payload— it then becomes plain that every pound of engine weight saved from this total by careful design and manufacture, is an additional pound made available for payload.

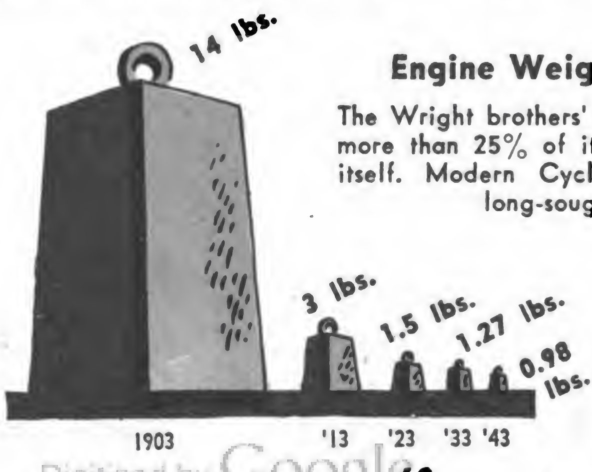
Therefore, one pound of engine weight saved for 150,000 miles, in transportation terminology adds up

to allow for the weight of heavy engines, an airliner over a period would find, for example, that it might have to make six trips instead of four — fly in back-and-forth trips perhaps 100,000 miles instead of 75,000 miles. Since operating costs for the additional trips will remain more or less constant, the additional trips will be additional costs. It has been figured that one pound weight saving is worth $50 per airplane per year to an airline operating two-engined aircraft. The figure is $250 for four-engined planes.

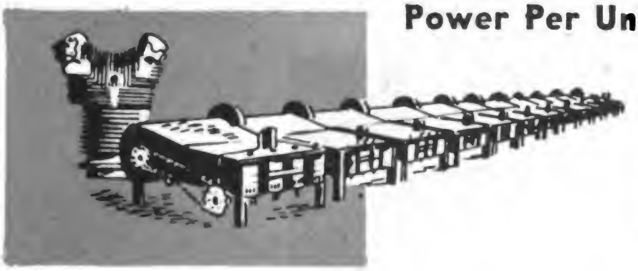
Wright Aeronautical's contributions in the field of weight reduc-

Engine Weight Per H. P.

The Wright brothers' first engine used up more than 25% of its energy propelling itself. Modern Cyclones, attaining the long-sought pound-per-horsepower, put all but a small fraction of their power into payload power.



tion go back through the years to the predecessors (through a series of mergers) of the present Cyclone-building company: the Wright brothers. The Wright brothers knew that they must have a power plant light in weight in proportion to horsepower. Finding none available in the engine market, they built their own. It made. In this step, it is interesting to note that some parts have actually been made stronger by reducing their weight, because the parts of lesser weight could be placed in a vibration frequency out of harmony with the surrounding engine parts — thus avoiding even the slightest danger of failure for this reason.



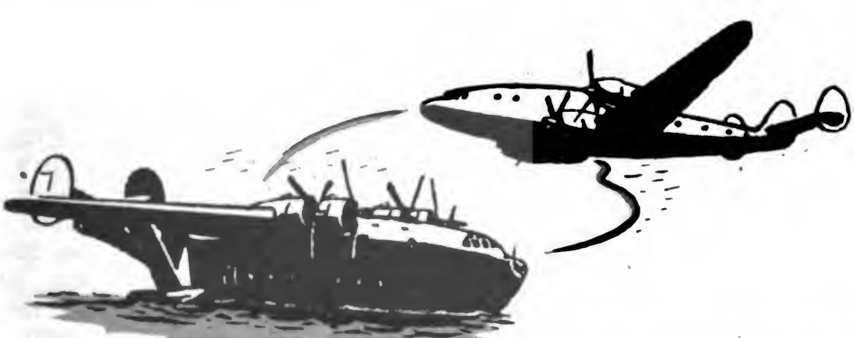
Power Per Unit of Space and Weight

The Wright brothers' engine developed 12 horsepower weighed 170 pounds. Today one Cyclone cylinder assembly, weighing less than 50 pounds, develops 135 horsepower.

weighed 14 pounds per horsepower. Since then, from year to year, the weight situation is steadily improving. In the latest engines, the weight-per-horsepower is in the neighborhood of one pound.

To attain this low weight per unit of power, the initial jobs must be done by Engineering, which designs the engines. This phase of the work necessitates not only shaping the parts on the drawing board to attain low weight; it also means selection of materials of such extremely high quality that their strength-per-pound represents a maximum. It also necessitates repeated test-running of engine models in the experimental test cells to learn by actual practice where additional economies in weight can safely and efficiently be

But weight reduction is also a consideration in manufacturing the engine. A finished cylinder, for example, weighs hardly one fourth as much as the original rough head casting and cylinder barrel forging. The completed crankshaft is a fly-weight part compared to the ponderous forging which is the raw material for the crankshaft-working machine tools. To attain a minimum of weight per unit of power, the completed parts must be as perfect as skilled workers can make them. Imperfect workmanship can mean that engine parts will not possess the strength intended for them. Reduced in strength, therefore, the engine automatically becomes **proportionately** heavier.

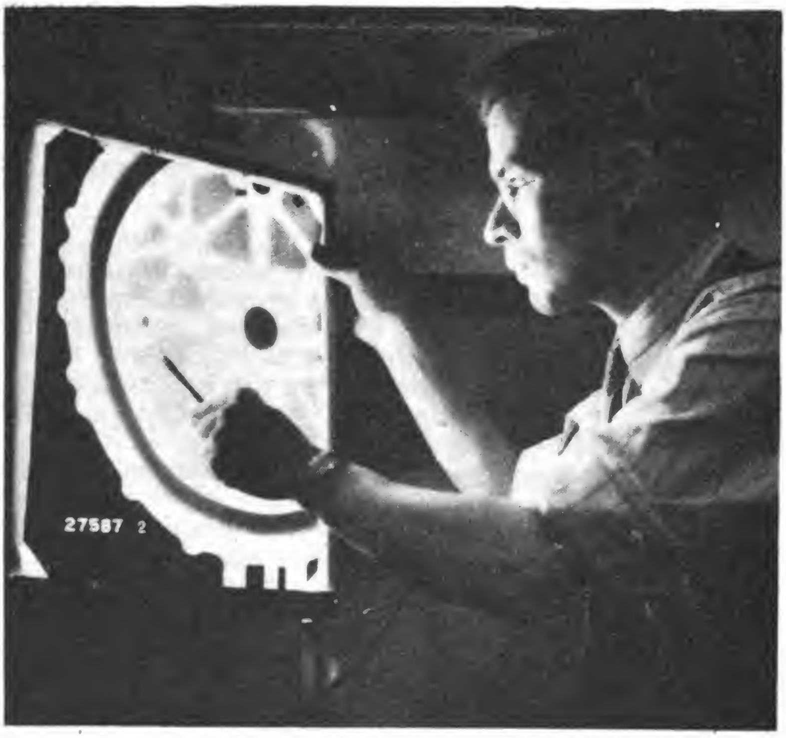


Wright Powered First super-transports

No. 36 — Why Quality?

Any thorough student of the radial aircraft engine such as a Cyclone or Whirlwind must grasp the fact that this kind of power plant is a very special piece of machinery, not only in design and function — but, at the very outset, in the materials of which it is made.

The piston head of a Cyclone engine running at take-off power is subjected to a total maximum gas load of approximately 15 tons 21 times every second. The master articulated rod is subjected to a bending load, because of the action of the articulated rods, equal to that which would be produced



X-Ray plays part in guard against defects

The ponderous stationary power plant, with thick cylinder walls and heavy flywheel, can afford to have parts bigger and heavier than actually required for power output. Because they may be thicker and heavier, it is not essential to use top-grade materials because size can make up for some lack of quality.

With the aircraft engine, size and weight limitations constitute an unwavering obstacle to putting more weight or size into engine parts than their maximum job (plus a reasonable safety margin) requires. Quality must be present to make up for the lack of quantity.

What Engine Withstands

To realize what the engine must withstand—to appreciate the need for high quality materials — consider such facts as these:

by supporting the rod at its big end as a cantilever and hanging 2,500 pounds at right angles to the axis of the rod at the piston pin eye. This load occurs once each revolution. The maximum torque transmitted by the crankshaft is approximately 3775 foot pounds. This is the twisting equivalent of a 3775 pound load hanging on a wrench one foot long. Crankpin bearing pressures in a dive may reach 6000 pounds per square inch. Cylinder head temperature may reach 550 deg. F. and the temperature of the cylinder base at the crankcase may reach 325 deg. F. Engines are drenched with cold rain in flight. When landing, taxiing, or at anchor on salt water, engines are often considerably wetted with this highly corrosive liquid.

Responsible, to a large extent,

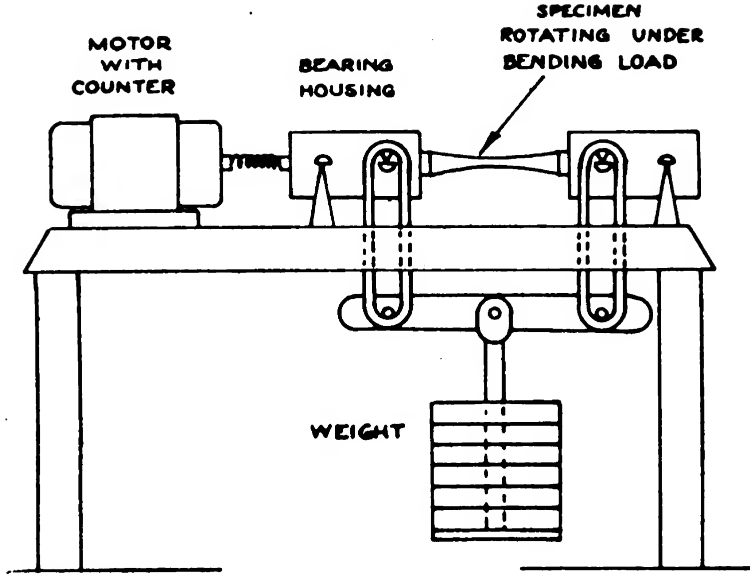


Diagram of Test Machine—For Strength Study

for assuring quality of engine materials is the Materials Laboratory. After engines and engine parts have been designed, the Materials Lab not only assures that materials for new models are up to specifications; it also endeavors to collaborate in further engine improvement by making existing materials even stronger.

Numerous Tasks

The separate tasks of the Materials Lab are probably more numerous and more varied than those of any other unit in the engine building organization. The Laboratory takes the X-ray photograph of all master rod bearings, examines these prints to assure that no defects are permitted to get by, and files the X-ray pictures permanently.

The Laboratory uses a photomicrograph to examine metal grain structure minutely . . . the tensile-testing machine to discover the strength of samples of each incoming quantity of bar stock . . . special equipment to measure the ability of valve springs to flex and unflex . . . the spectrograph, to analyze material samples by burning them in an electric arc and studying the wave lengths of light emitted thereby . . . the salt spray box, to subject metal samples to the corrosive effect of salt water spray . . . the centrifuge and other laboratory equipment to measure the properties of lubricating oil and gasoline received for use in test cell engine operation.

The Materials Laboratory, spreading over an entire floor in one of the Wright Aeronautical plants, is actually a number of separate materials laboratories in one; the Lab reaches beyond this floor too, its technicians standing by in the foundries for example, to maintain control over heat recording instruments, and studying samples of metal poured for castings. Within the foundry is a completely equipped experimental heat-treating plant, a photo studio, an X-ray department, a chemical laboratory, an experimental plating department, and a physical testing section. The Laboratory is a gauntlet that engine materials and sample engine parts must run before they go on to take their places in the completed engine — which, in turn, must pass the scrutiny of the toughest hurdle of all, the test cells.

Wright was First to attain pound-per-H.P.

No. 37 — The Propeller

While ENGINOLOGY will not make an engineer or even an "expert" of any of its readers, the stories to date have been planned to give non-technical-minded readers an introduction to the power plant. Having that introduction, the logical question arises: just what makes possible an engine's power to propel an airplane — in other words, how do the other members of the team of aircraft, engine, and propeller operate?

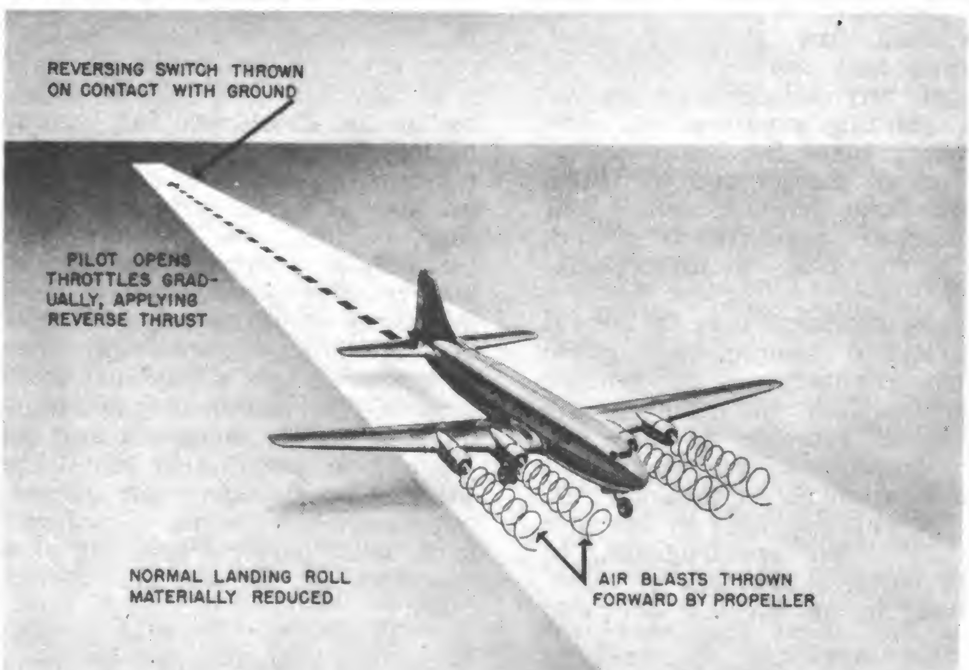
We already know the role of the engine. Its job is to produce power and present that power in the form of the rotary motion of the propeller shaft — to the propeller.

In building an engine, the manufacturing process provides for the joining of propeller to prop shaft by working into the shaft a series of grooves or "splines." Around the inner circumference of the propeller hub is a mating pattern of splines which permit the propeller to be placed so that the prop shaft becomes its axis, but does not permit the propeller to turn about the prop shaft.

Basically the principle of aircraft propulsion of the type served by Cyclones is simple. The propeller works on the principle of a screw. Screws date back to the days of Archimedes. Think of a corkscrew which pulls itself further along into a cork as it is turned, think of the screw propeller of a motorboat which pulls itself and its boat through the water. These operate on the same basic principle as aircraft propellers.

In revolving swiftly in the air, driven by an aircraft engine, a propeller — like the corkscrew moving through the cork, or the motorboat propeller moving through the water, pulls its aircraft along the ground. As the speed along the ground increases, the airplane attains flying speed, its wings bearing it aloft where the churning of the propeller through the air continues to move it swiftly enough to keep it airborne.

What causes the wings to lift the airplane off the ground and maintain flight is in itself the subject of another story. Looking

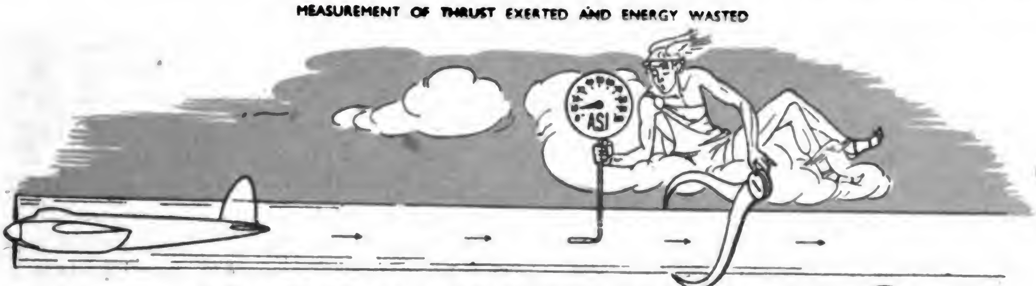


Propellers for modern transport planes, far more than mere blades, embody equipment for changing pitch, "de-icing" and in the case of a new design perfected by the Curtiss Propeller Division of the Curtiss-Wright Corporation, braking on the ground by reversing the pitch.

further at the propeller, it is of importance to notice that this member of the team, aircraft-engine-propeller, in modern high-powered planes is no longer a simple carved shaft of wood. The modern heavy-duty propeller, more than a mere set of blades, is an intricate mechanism.

trolled by the pilot, provides the aircraft with a means of obtaining maximum thrust for takeoff when force rather than speed is essential. Once well in the air, the pitch-changing mechanism may so change the "bite" of the propeller into the air that high speed is obtained. It is much like the transmission sys-

MEASUREMENT OF THRUST EXERTED AND ENERGY WASTED



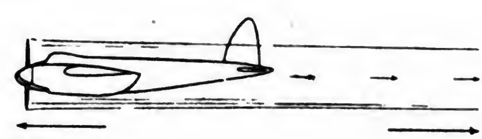
Thrust exerted is proportional to mass of slip per second multiplied by its velocity
Energy wasted is proportional to mass of slip per second multiplied by square of its velocity
Useful power exerted is proportional to thrust multiplied by speed of aeroplane.

Considering, for example, the propeller made by the Propeller Division of Curtiss-Wright, the modern propeller possesses blades which can be changed to any desired "pitch." "Pitch" is the term used to describe the angle at which the propeller blades bite into the air. To illustrate differences in pitch think of the cork-screw which turns itself into a cork with but comparatively few turns on the handle. Then think of a stove bolt with its much shallower pitch which requires many turns before it is fully tightened into its nut.

This modern airplane propeller, as a mechanism that can be con-

tem of an automobile by which the auto climbs a steep hill in low gear and hurries along a level stretch in high gear.

In addition, the propeller has built-in equipment for "de-icing," a function that keeps ice at icing altitudes from so encumbering the propeller that its shape is destroyed.



Power used in propelling aeroplane

No. 38 — Why a Plane Flies

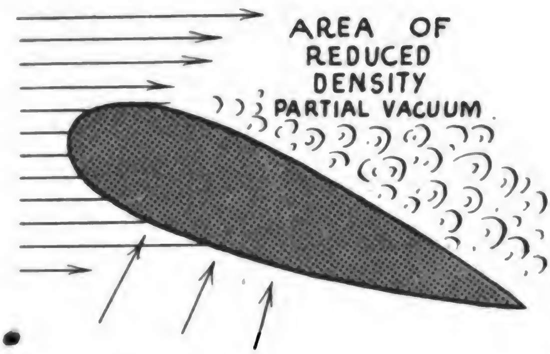
The facts about aircraft engines are closely related to the facts about aircraft. It is a three-way partnership: the engine supplies the force which moves the aircraft; the plane provides the wings and control surfaces; the air through which the plane moves becomes the element upon which the aircraft is borne in flight.

Move a large piece of cardboard swiftly through the air with its forward edge tilted upward. Immediately, it will be noticed that the cardboard tends to rise. Something has happened to lift that cardboard. As if grasped by unseen hands, it tends to move upward at an angle corresponding to the angle of upward tilt. Since this cardboard, a flat surface, is subject to the lifting effect — and is potentially able to carry weight with it in its rise — why not make aircraft wings flat? Why is the cross-section of a wing characteristically curved, with the wing thick at the leading edge and thin toward the trailing edge?

The answer brings one into the field of aerodynamics, the study of principles governing the movement of aircraft in flight.

Actually, a flat-surfaced wing could support an aircraft in flight, just as a wooden wheel could suf-

fice to move an automobile along a highway. But just as the rubber-tired disc wheel is vastly more



The wing section: note that the distance over the upper surface, from leading edge to trailing edge, is greater than the distance from front to back along the lower surface.

efficient in strength and load-carrying capacity, so the wing section scientifically curved is more effective for aircraft.

In considering what causes an aircraft wing to develop lift, we begin with the knowledge that air is not empty space. It is space cram-filled with particles of matter, microscopic units of oxygen, nitrogen, and other gases and solids. Like marbles in a gold-fish bowl, these particles offer resistance by their weight and mass; they move in to fill any holes in their ranks made by removing some of their number — finally, like water moving against a mill-wheel, they exert force in proportion to their net volume, density and velocity.

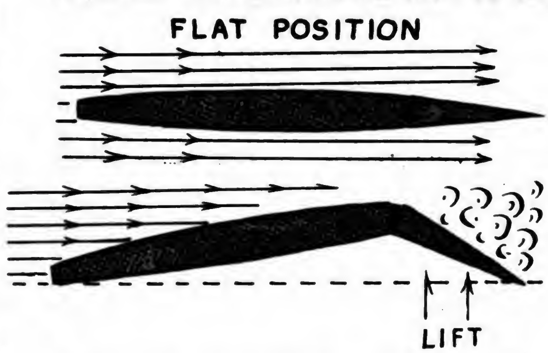
With this picture of air as a mass of matter, it can be seen that we live literally within an "ocean" of air. Now, think of a surface such as an aircraft wing in that ocean of air. In still air this wing will tend to remain at rest in any position. It is like an object placed in the middle of the fish bowl of marbles; pressures are equal above and below and on all sides of the wing; they cancel out one another.

Begin to move that aircraft wing through the air however, and aerodynamic principles become applicable which cause an "unbalance" of the pressures on top and bottom of the wing. The "unbalance" results in lift, lift which varies according to the cross-sectional shape of the wing and its speed in relation to the air around it.

The swift movement of the wings through the air causes the air to rush along the bottom and top of these wings. Because the lower surface is flat (or, in some wing types, comparatively flat), the air moves along without serious disturbance, or "turbulence." Above the wing, however, the air is disturbed; it eddies and turns beyond the curve in the wing, leaving the space at that point a less dense portion of air than all surrounding air. Because of this inequality of pressures below and above the wings, the plane's wings are supported. Literally, heavier-than-air flying is made possible by unbalancing pressures.

To express the mechanics of lift in more precise terms, study the following:

"Lift" occurs by operation of a law of aerodynamics which — reduced to mathematical terms — holds that pressure plus velocity equals a "constant." With this in mind, think now of the air stream moving above and below the wing section. The bottom surface of the



Ailerons, mounted at the trailing edges of wings, enable the air craft to maintain side-to-side balance and to bank on turns, by giving one wing more "lift" than the other.

wing is generally flat; from its leading edge to its trailing edge is a straight line — or a gentle curve. The top surface, on the other hand, is curved. From leading edge to trailing edge over the top of the wing is a longer distance than that along the underside of the wing. To arrive at the trailing edge at the same time, a particle

of air below the wing can travel more slowly than air above the wing; air above the wing has that longer distance to travel.

Here is an example of the workings of this formula, as applied to the aerodynamics of lift:

The "constant" selected for a given wing section is represented by 15.

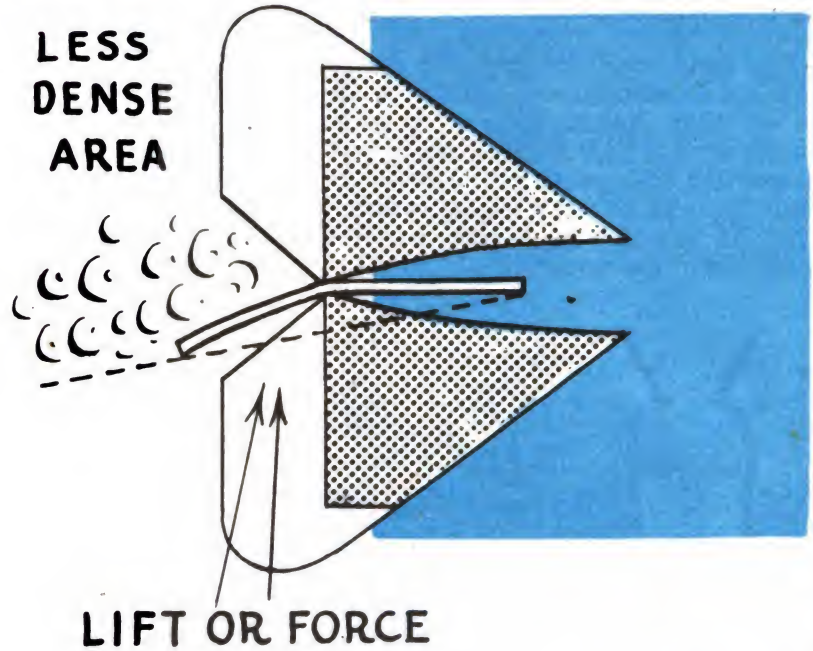
Air moving along the top of a wing must move at a rate faster than air along the bottom of the wing, so "V" in this example is arbitrarily set down in the ratio of 8 for the upper surface and 4 for the underside. Therefore:

For the upper surface: P plus 8 equals 15.

For the lower surface: P plus 4 equals 15.

Pressure for the upper surface is therefore 7 units; for the lower, 11 units. Pressure upon the bottom of the wing is thus shown to be greater than pressure on the top of the wing. To balance pressures, top and bottom, pressure from below moves upward, pushing upon the wing as "lift."

This formula is a mathematical expression of the principle of lift. Most important is the principle itself: lift results from a **difference in pressures** above and below the wings.



The rudder causes the airplance to move to left or right through an unbalancing of pressures related to the unblancing that accounts for lift.

Wright Powered First flights over both Poles: first N. Y. to Paris: first long-range to S. America

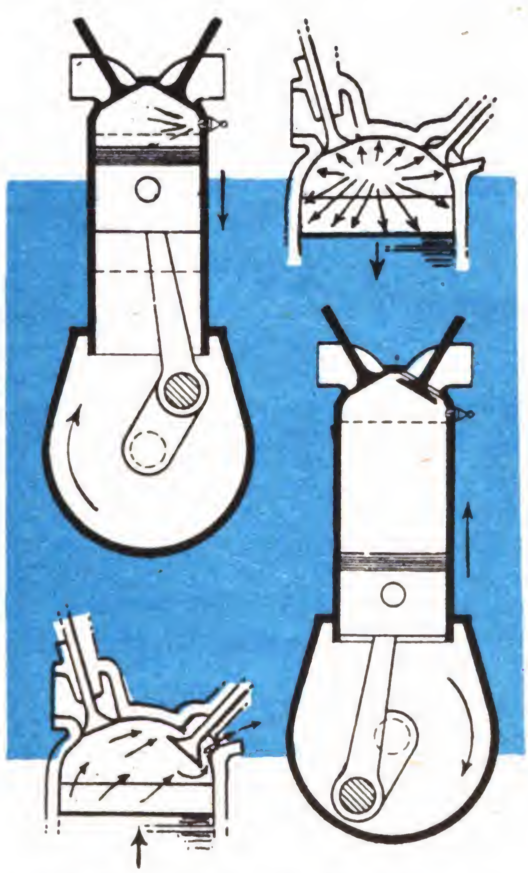
No. 39 — A Quick Review

Since the first of these stories about aircraft engines was published about a year ago, ENGINOLOGY has been read as instructional material by tens of thousands of persons; it has appeared in booklet form for distribution not only to Wright Aeronautical employees but to aviation enthusiasts and aircraft engine mechanics in training in this country and abroad.

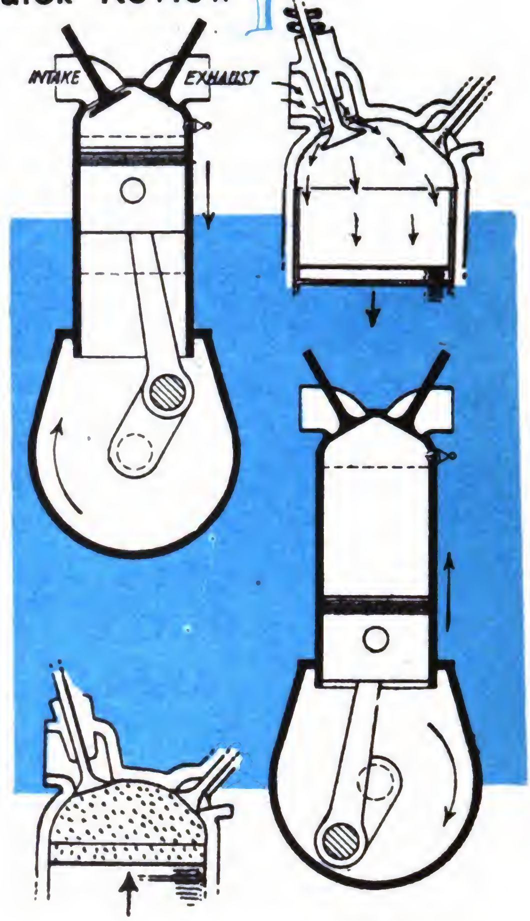
To this large "student body" of ENGINOLOGY, a fair question seems to be: Has the information in ENGINOLOGY helped? Have the readers of ENGINOLOGY acquired a general working knowledge of the aircraft radial power plant?

The best way to find out is to hold an examination. Here is a set of quiz questions for a self-review of ENGINOLOGY so far—answers to the questions appear in small type at the end of the story.

1.—Is the steam engine an internal combustion engine?



A—Top Sketches; B—Bottom



C—Top Sketches; D—Bottom

2.—What is the function of valves such as intake and exhaust valves in the internal combustion engine?

3.—Does the crankshaft operate on the principle of the crank on a well?

4.—Name some typical types (in terms of arrangements of cylinders) of internal combustion engines.

5.—What are some of the advantages of the radial air-cooled type over the inline type?

6.—Has the radial air-cooled engine been developed to the point at which some models weigh less than one pound per horsepower?

7.—In the diagrams below, which is the compression stroke? Which is the power stroke? Which is the intake stroke? Which is the exhaust stroke?

8.—Name two functions of the master rod.

9.—How much work is represented by one horsepower?

10.—What are some horsepower ratings of aircraft radial engines, as represented by Whirlwinds and Cyclones?

11.—What does the impeller in a supercharger do?

12.—Which is nearer to the maximum speed of the impeller: 2,500 revolutions per minute or 25,000 revolutions per minute?

13.—Before combustion takes place in the engines, what must be done to the mixture of fuel vapor and air?

14.—How many spark plugs serve each cylinder in the average automobile engine? In the aircraft engine cylinder?

15.—Which is nearer to the correct number of horsepower developed in a single Cyclone cylinder: 10 h.p.; 50 h.p.; 75.5 h.p.; 100 h.p.; 135 h.p.?

16.—What is the name of the engine part which carries current to the spark plugs?

17.—What is the function of the dynamic damper and where is it located in the engine?

18.—Pinions and trunnions are part of what system in the engine?

19.—What is meant by reduction gearing, and what is its purpose?

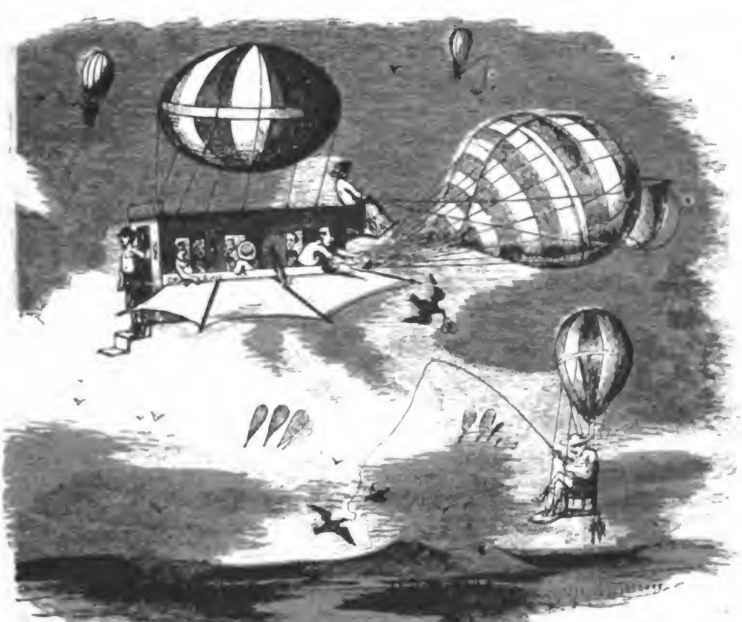
20.—What mechanism causes an exhaust valve to open and close at the right time?

21.—In an engine which is operating at 2,400 r.p.m., how many times a minute does a single intake valve open and close?

22.—Name two functions of the crankcase in a radial aircraft engine.

ANSWERS

1.—No. 2.—Valves control entrance of combustibile gasses and discharge of burned gasses. 3.—Yes. 4.—Inline, "V", "X", "W", horizontally opposed, radial. 5.—Lighter weight, simpler construction, easier maintenance. 6.—Yes. 7.—A-intake; B-compression; C-power; D-exhaust. 8.—Master rod is articulated rod for its own cylinder and collects power from other cylinders in the same row. 9.—One horsepower can lift 33,000 pounds one foot in one minute. 10.—400 h. p.; 1200 h. p.; 1600 h. p.; 1700 h. p.; 2000 h. p.; 2200 h. p. 11.—Impeller compresses air on way to combustion chamber. 12.—25,000 r.p.m. 13.—It must be compressed. 14.—One in auto; two in aircraft. 15.—135 h.p. 16.—Ignition harness. 17.—Dampens a phase of engine vibration; mounted on crankshaft crankcheek. 18.—Reduction gears. 19.—Reduction gearing is a system of gears which change one speed of rotation to a lower speed; serves to turn propeller at appropriate r.p.m. 20.—Cams move push rods, push rods move valves through rocker arms. 21.—1200 times. 22.—Crankcase is a structural member, helping to hold engine together; it is also a container.



THE PUBLIC HIGHWAY—TRAVEL IN THE 30TH CENTURY.

IMAGINATION POWERED THIS ONE—Indicative of man's age-long yearning to fly, this artist's drawing of the 1870's depicts man-carrying balloon towed by other balloons.

No. 40 — The Cyclone 7

Newest member of the Cyclone family is the Cyclone 7. As its designation implies, it is a seven-cylinder engine. Developing 700 horsepower from low octane fuel—and greater power from higher octane fuel—this power plant fits into a category of horsepower relatively untouched in recent years.

Look at the power curve on page 50. The curve is a reminder that the output of Cyclone engines—for almost ten years — has been at or above the 1,000 horsepower mark. The Whirlwind engine's power rating, falling at the opposite end of the scale, has been around the 500 horsepower level. Other aircraft engine manufacturers have, for the most part, followed the same trend: the high-horsepower engines have passed the 700 horsepower mark in their surge to much greater output levels; the lower horsepower engines — under the 500 horsepower mark — have remained at those levels, becoming increasingly efficient but no more powerful.

Demand Is Factor

Demand accounts for this apparent gap in the horsepower ranks. As airplanes grew larger and increased their range and load-carrying ability, they needed engines of greatly increased power. At the same time engines in the under-500-horsepower class continued to be needed in vast quantities for small personal planes, and trainers.

With the increased use of air transport in long-range, heavy-duty operations, a brand new demand has started to grow. This demand—potentially important right now in military flying—calls for planes in the "middleweight" class, to haul personnel and cargo to points at which such loads may be transferred to the heavy-duty, long-range planes. The Cyclone 7 was designed to answer this need.

As this second printing of the second edition of Enginology goes to press in April, 1945, a prototype model of the Cyclone 7 has been test-flown in a Curtiss-Wright aircraft. The demonstration has indicated satisfactory power output, fuel economy, and smoothness.

Basically, the Cyclone 7 is the latest model of the Cyclone 9—but with seven new-type cylinders instead of nine. The Cyclone 9 (see page 44) now powers more than 80 per cent of the nation's airlines, powers such warplanes as the Boeing Flying Fortress, Douglas Dauntless, and Grumann Wildcat.

Close resemblance of the Cyclone 9 makes possible interchangeability of many parts of the nine-cylinder and seven-cylinder types, simplifies maintenance problems, and makes possible economy in manufacture.

Uses Low-Octane Fuel

The low-octane fuel which can be burned in the Cyclone 7 will enable operators to save expenses on gasoline; for many of the transport jobs to be done by planes in the 700-horsepower range, high octane fuel is not important. That the savings can become appreciable is indicated by the fact that fuel costs account for twelve per cent of air transport operating expenses.

The Cyclone 7 will make use of new-type forged cylinder heads to provide maximum strength, ruggedness, and cooling efficiency. Cylinder barrels incorporate aluminum fins for improved cooling; this in turn assures longer piston ring life and improved piston lubrication.

Another feature is a valve gear lubrication system which makes use of a series of external oil tubes to increase the lubrication of valves. To improve lubrication within the engine, oil jets have been provided in the engine's crankcase to direct a continuous flow of oil into each cylinder.

The Cyclone 7 is provided with a two-speed supercharger drive. The higher supercharger ratio, 8.686 to 1, is adequate for development of maximum engine power at high altitude airports. The lower supercharger ratio, 7.208 to 1, is recommended for use in supplying extra power for high performance at low altitude.

U. S. ARMY PLANES POWERED WITH WRIGHT ENGINES

Manufacturer and Army Designation	*Mission*	*Wright Engine*	*H.P. Per Engine*
Boeing B-29 Super Fortress	Super-Bomber	4 Cyclone 18's	2,200
Boeing B-17 Flying Fortress	Heavy Bomber	4 Cyclone 9's	1,200
Curtiss A-25 Helldiver	Dive Bomber	1 Cyclone 14	1,700
Douglas A-20 Havoc	Attack Bomber	2 Cyclone 14's	1,600
Douglas C-49	Cargo	2 Cyclone 9's	1,200
Douglas P-70 Havoc	Fighter	2 Cyclone 14's	1,600
Douglas A-24 Dauntless	Dive Bomber	1 Cyclone 9	1,000
Lockheed C-60 Lodestar	Cargo	2 Cyclone 9's	1,200
Lockheed C-69 Constellation	Transport	4 Cyclone 18's	2,200
Lockheed AT-18 Hudson	Gunnery Trainer	2 Cyclone 9's	1,200
Martin A-30 Baltimore	Attack Bomber	2 Cyclone 14's	1,600
North American B-25 Mitchell	Medium Bomber	2 Cyclone 14's	1,700

U. S. NAVY PLANES POWERED WITH WRIGHT ENGINES

Manufacturer and Navy Designation	*Mission*	*Wright Engine*	*H.P. Per Engine*
Curtiss SB2C-1 Helldiver	Scout Bomber	1 Cyclone 14	1,700
Curtiss SNC-1 Falcon	Scout Trainer	1 Whirlwind 9	450
Douglas SBD-3 Dauntless	Scout Bomber	1 Cyclone 9	1,200
Douglas R4D-2 Skytrooper	Transport	2 Cyclone 9's	1,200
Eastern Aircraft TBM-1 Avenger**	Torpedo Bomber	1 Cyclone 14	1,700
Eastern Aircraft FM-2 Wildcat**	Fighter	1 Cyclone 9	1,350
Grumman TBF Avenger	Torpedo Bomber	1 Cyclone 14	1,700
Grumman J2F-5	Utility	1 Cyclone 9	1,200
Lockheed R50-4 Lodestar	Transport	2 Cyclone 9's	1,200
Lockheed PBO-1 Hudson	Patrol Bomber	2 Cyclone 9's	1,200
Martin PBM-1 Mariner	Patrol Bomber	2 Cyclone 14's	1,600
Martin PBM-3 Mariner	Patrol Bomber	2 Cyclone 14's	1,700
Martin Mars	Patrol Bomber	4 Cyclone 18's	2,000
North American PBJ Mitchell	Patrol Bomber	2 Cyclone 14's	1,700
NAF N3N-3	Trainer	1 Whirlwind 7	235

**Grumman designed and developed

R. A. F. PLANES POWERED WITH WRIGHT ENGINES

Type of Plane	*British Designation*	*Mission*	*Wright Engine*	*H.P. Per Engine*
Boeing B-17*	Fortress I	Heavy Bomber	4 Cyclone 9's	1,200
Brewster SB2A-1†	Bermuda	Dive Bomber	1 Cyclone 14	1,700
Canadian Car and Foundry SBW-1†	Helldiver	Scout Bomber	1 Cyclone 14	1,700
Canadian Vickers	Delta II	Photographic	1 Cyclone 9	890
Douglas DB7-A‡	Havoc II	Night Fighter	2 Cyclone 14's	1,600
Douglas DB7-B‡	Boston I, II, IIIA	Bomber	2 Cyclone 14's	1,600
Grumman GB36-A‡	Martlet I, IV	Fighter	1 Cyclone 9	1,200
Grumman TBF†	Tarpon	Torpedo Bomber	1 Cyclone 14	1,700
Lockheed 14‡ 414-40	Hudson I and II	Bomber	2 Cyclone 9's	1,100
Lockheed 414-56‡	Hudson III	Bomber	2 Cyclone 9's	1,200
Vega B-37*	Ventura	Bomber	2 Cyclone 14's	1,700
Lockheed C-60*	Lodestar II	Transport	2 Cyclone 9's	1,200
Martin A-30*	Baltimore	Dive Bomber	2 Cyclone 14's	1,600
Vultee A-31C*	Vengeance III	Dive Bomber	1 Cyclone 14	1,600
Vultee A-35B*	Vengeance IV	Bomber	1 Cyclone 14	1,700
North American B-25C*	Mitchell	Medium Bomber	2 Cyclone 14's	1,700

‡ Manufacturers Designation   * U.S. Army Designation   † U.S. Navy Designation

DOMESTIC AIRLINES LIST

Airline	*Commercial Slogan*	*Home City*	*Territory*
*Alaska Airlines	Serving the Top of the World	Anchorage	Alaska only—from Juneau north and inland
*All American Aviation, Inc.		Wilmington, Del.	Pa., W. Va., and Washington, D. C.
*American Airlines, Inc.	Route of the Flagships—Overnight Coast-to-Coast	New York, N. Y.	Transcontinental, also international service to Mexico and Canada
*Braniff Airways	From the Great Lakes and the Rockies to the Gulf — It's "Friendly" Transportation	Dallas, Texas	Denver and Chicago to Texas
*Chicago & Southern Air Lines		Memphis, Tenn.	Chicago to southern points
*Colonial Airlines	Serving two countries	New York, N. Y.	Northeastern U. S. and eastern Canada
*Delta Air Lines	The Trans-Southern Route	Atlanta, Ga.	Southeastern U. S.
*Eastern Air Lines			New York to Florida and Texas
Mid-Continent Airlines	The Great Plains Route	Kansas City, Mo.	Mid-West
*National Airlines	The Buccaneer Route	Jacksonville, Fla.	New York to Florida and New Orleans
*Northeast Airlines		Boston, Mass.	Northeast U. S.
Northwest Airlines	Shortest, fastest between Chicago and Seattle	St. Paul, Minn.	Chicago to west coast
*Pan American World Airways	The System of the Flying Clipper Ships—America's Merchant Marine of the Air	New York, N. Y.	Southern U. S. to Latin America, also service to Hawaii, Bermuda, Canada, Alaska
*Pennsylvania-Central Airlines		Washington, D. C.	Central eastern states
*Transcontinental & Western Western Air, Inc.	Shortest, fastest, coast-to-coast	Kansas City, Mo.	Entire U. S.
United Air Lines	The Main Line Airway	Chicago, Ill.	Transcontinental
Western Air Lines and subsidiary, Inland Air Lines		Hollywood, Calif. Hollywood, Calif.	West coast Montana, Wyoming, Colorado

*Use Wright-powered planes

REPRESENTATIVE AIRLINES BASED OUTSIDE OF U. S.
(All use Wright-powered equipment)
U. S. POSSESSIONS LINES LIST

Airline	*Home City*	*Territory*
Anchorage Air Transport	Anchorage	Alaska
Alaska Airmotive	Fairbanks	Alaska
Alaska Airlines (Star)	Fairbanks	Alaska
Ellis Air Transport	Ketchikan	Alaska
Ferguson Airways Inc.	Kotzebue	Alaska
K-T Flying Service	Honolulu	Hawaii
Pacific Alaska Airways (Pan Am)	Fairbanks	Alaska
Peck and Rice Airways	Bethel	Alaska
(1) Philippines Aerial Taxi Company	Manila	Philippine Islands
Pollack Flying Service	Fairbanks	Alaska
Prospectors Airways	Fairbanks	Alaska
(6) White Pass and Yukon Railroad		Alaska

FOREIGN FLAG AIRLINE LIS.

(Using Wright-powered equipment)

Airline	Home City	Territory
Aer Lingus Teoranto	Dublin	Eire, England
Aeronaves de Mexico	Mexico City	Mexico
(5) Aero O/Y	Helsinki	Finland & Northern Europe
Aerovias de Guatemala	Guatemala City	Guatemala
Aerovias del Ecuador Panagra	Guayaquil	Ecuador
Aerovias Venezolanas SA (AVENSA)	Caracas	Venezuela
Aerovias Nacionales Colombianas SA (AVIANCA)	Barranquilla	Colombia
Air France	Paris & Algers	Europe & Africa
Aktiebolaget Aerotransport (ABA)	Stockholm	Sweden & Northern Europe
(1) Ala Littoria	Rome	Italy, Europe, Africa
(1) American Eastern Avia. Co.	Hongkong	Far East
Ansett Airways, Ltd.	Essendon	Australia
Australian National Airways Pty Ltd.	Melbourne	Australia
(1) Avio Linee Italiane S. A.	Milan	Europe & Italy
British Columbia Airways	Victoria	Western Canada
British Overseas Airways (BOAC)	London	Europe, Africa, Middle East, India, Trans-Atlantic
British West Indies Airways (TACA)	Port-of-Spain	Trinidad
(2) British Yukon Navigation Company	Vancouver	W. Canada
Brooks Airways Ltd.	Prince Albert (Sach)	Western Canada
(3) Canadian Colonial Airways	Montreal	Canada and to N. Y. C.
Canadian Airways Ltd	Winnipeg Laca La Tortue	Canada
China National Aviation Corp. (CNAC)	Chungking	China — India
Civil Aeroflot of U.S.S.R.	Moscow	U. S. S. R.
Compania Aeronautica Francisco Sarabia	Merida	Mexico
Compania iberia de Transportes Aereos	Madrid	Spain & North Africa
Compania Nacional Cubana de Aviacion	Havana	Cuba
Compania Mexicana de Aviacion SA (CMA)	Mexico City	Mexico—U. S. A.—Cuba
(4) Compania Transportes Aereos del Pacifico SA	Mexico City	Mexico
Comunicaciones Aereas Vera Cruz	Vera Cruz	Mexico
(7) Correio Aereo Nacional	Rio de Janeiro	Brazil
Compania de Transportes Aereos Centro Americanos (TACA)	San Jose	Costa Rica
Expreso Aereo Inter-Americano	Havana	Cuba—U. S.—Mexico
Guinea Airways Ltd.	Adelaide	Australia—New Guinea
Kingsford Smith Air Service Ltd.	Mascot N.S.W.	Australia
K. L. M. (Koninklijke Luchtvaart Maatschappi)	London	Europe & Netherlands West Indies
(1) K. N. I. L. M.	London	Europe & Netherlands East Indies
L. A. P. E. (Lineas Aereas Postales Espanolas	Madrid	Spain
L. A. R. E. S.	Bucharest	Rumania & Europe
Linea Aerea Sur-Oeste	Buenos Aires	Argentina
Linea Aerea Nacional de Chile	Santiago	Chile
Mackenzie Air Service	Edmonton	Canada
(1) Mongolian Transport (Far East Fur Transport		Mongolia

Airline	Home City	Territory
Navegacao Aerea Brasileira S.A. (N.A.B.)	Rio de Janeiro	Brazil
Primeras Lineas Uruguayas de Navegacion Aerea	Montevideo	Uruguay
Servicio Aereo Colombiano (now part of AVIANCA)	Medellin	Colombia
S.A.B.E.N.A.	Brussels	Belgium, Europe—Africa
Scottish Aviation Ltd.	Glasgow	Scotland and England
(1) Societe Francaise de Transportes Aeriens	Paris	France & Europe
Starratt Airways	Kenora (Ont.)	Canada
Stevens Aviation Ltd.	Wau	New Guinea
Swissair	Zurich	Switzerland
Transportes Aereos Transcontinentales	Mexico City	Mexico
TACA Airways S.A.	Panama City	Central America, South America, Caribbean
Trans Canada Airlines	Montreal	Canada
(8) Uruba-Medellin & Central Airways Inc.	Medellin & New York	Panama to Colombia
Wideros Flyveselskop	Oslo	Norway & Europe

(1) Airlines of former enemy countries or in occupied areas.
(2) Steam navigation Company, also operating airplane.
(3) Company has been taken over by Canadian Government but its route being operated.
(4) This Company now owned by Aeronaves de Mexico, S.A. Routes being operated.
(5) This Company's equipment includes engines secured from C.L.S. of Czechoslavakia.
(6) Railway Company, also operating airplane.
(7) Huge airmail line in Brazil operated by Military.
(8) This Company has been listed with Foreign Flag lines, but in reality it is incorporated in the U. S., operating from Panama to Medellin Colombia.

THE BOMB FERRY—TRAVEL IN THE 30TH CENTURY.

POWERED FLIGHT—as it was viewed by imaginative artists long before there was powered flight. Illustration from "Life Underground," published in 1873.

GLOSSARY

Accelerate: To increase the velocity or speed.

Adapter: A device used to join a part of one size to a part of another size.

Air-cooling: A system of cooling by air flow.

Air speed: The rate of motion of an aircraft relative to the air in which the aircraft is moving as distinguished from speed relative to the ground.

Alcohol de-icing: Spraying alcohol on propellers, windshield, etc., when ice is forming or when condensate is freezing, to melt ice, or to prevent the formation of ice.

Aligning bar: A tool used to line up two or more parts.

Back pressure: The pressure on the outlet side of the exhaust valve.

Baffles: A plate used to prevent the movement of a fluid in the direction which it would normally flow, and to direct it into the desired path.

Booster magneto: A magneto, usually hand operated, used to supply high tension current to the spark plug at starting. The magneto generates electricity.

Booster pump: An auxiliary pump which is inserted in a closed system to increase the pressure of the liquid in some part of the circuit.

Bottom center: The position of a piston when it is farthest from the cylinder head.

Brake horsepower, B.H.P.: The effective or useful horsepower developed by an engine, as measured by a brake applied to the driving shaft.

Brake mean effective pressure, B.M.E.P.: The average pressure in a cylinder during engine operation which, if exerted on each piston constantly during their power strokes, would cause the engine to develop brake horsepower.

Breaker point: Contact point actuated by a cam to break the primary circuit in the magneto and thereby cause a current surge in the seconday circuit which produces the ignition spark.

Breather: A mechanism which equalizes crankcase pressures with atmospheric pressure.

By-pass valve: A valve by which the flow of fluid in a system may be directed past some part of the system through which it normally flows.

Cam: An eccentric projection or lobe on a revolving shaft or ring, shaped so as to give some desired motion to a follower, which is usually returned by a spring; used as means of actuating engine valves.

Cam lift: The distance which a cam lifts the cam follower.

Carburetor air scoop: A device used to gather air into the induction passage.

Carburetor discharge nozzle: A part of the carburetor which sprays the metered fuel into the air stream in the induction passage.

Carburetor economizer: A needle valve which provides a richer mixture at full throttle for maximum power and permits a leaner mixture at cruising speeds for maximum economy.

Carburetor needle valve: An elongated valve used to restrict the flow of fuel in a passage in the carburetor.

Cartridge starter: A starter which turns the engine by means of pressure, acting on a piston, from an explosive charge in a specially designed chamber.

Center of gravity: That point in a body at which its weight may be taken to act and at which the

body may be supported in neutral equilibrium.

Check valve: A self operating valve, fitted in a passage to prevent fluid flow under certain gravity or pressure conditions.

Clutch: A device by which two shafts or rotating members may be connected or disconnected, either while at rest or in relative motion; example, starter clutch.

Combustion chamber: The space above the piston when at top center in which the initial combustion occurs.

Compensated magneto: A magneto designed to fire the charge at the same position of piston travel for each cylinder. This requires a slight departure from uniform firing to compensate for radial engine articulated rod construction.

Compression stroke: The stroke during which the fuel-air mixture is compressed by the upward stroke of the piston while both the intake and exhaust valves are closed.

Constant speed propeller: A propeller which maintains a constant rpm under varying load conditions by automatically changing the pitch of the propeller blades.

Controllable pitch propeller: A propeller, the blade angles of which may be adjusted to any desired position during flight.

Cowling: A casing of sheet metal placed around an air-cooled engine to direct the cooling air on to the cylinders and reduce drag.

Crankcheek: That portion of the crankshaft from which the counterweight is suspended.

Crankpin: That portion of the crankshaft on which the master connecting rod is assembled.

Critical altitude: Critical altitude is the maximum altitude attainable with the engine developing a given power at full throttle and at a given rpm.

Cylinder barrel: The tubular part of the cylinder in which the piston moves.

Cylinder head: The closed end of the cylinder.

Data plate: A rectangular metal plate mounted on the engine containing important engine information.

Detonation: The harmful spontaneous combustion or compression ignition of part of the compressed charge in a cylinder.

Direct drive: A drive effected from the crankshaft extension without any intervening gear drive.

Distribution chamber: A part of the induction system surrounding the impeller and diffuser plate from which fuel-air mixture is distributed to the intake pipes and cylinders.

Dynamic damper: A floating counterweight suspended from the crankcheek to reduce engine vibration.

Dynamic suspension: A Wright patented method of flexible engine mounting designed to reduce airplane vibration by allowing restrained engine motion.

Engine accessory: A device installed on an engine essential to engine or airplane operation or comfort of the flight personnel. Includes units such as starter, generator, magneto, vacuum pump, hydraulic pump, fuel pump.

Engine sling: A cable arrangement used with a chain hoist for raising the engine to a horizontal position.

Engine warm-up: The running of an engine at low speeds immediately after starting to insure proper lubrication, and the gradual and uniform warming of engine parts prior to engine operation at high power and speed.

Exhaust collector ring (exhaust manifold): A metal duct with connections to each exhaust port used for the purpose of discharging all exhaust gases through one or two pipes.

Exhaust port: The port or opening in a cylinder through which the exhaust gas is discharged.

Feathering (propeller): The action of turning the blades of a propeller to increase the pitch sufficiently to eliminate windmilling.

Fin: Thin projecting strips of metal formed integral with, or fastened to, an air-cooled object to increase the cooling area.

Firewall: A protective wall in an airplane located between an engine and the fuselage.

Firing order: The sequence in which the cylinders of a multi-cylinder engine are fired.

Four stroke cycle engine: An engine cycle completed in 4 piston strokes consisting of: 1. intake, 2. compression, 3. power, 4. exhaust.

Fuel-air ratio: The proportion by weight of fuel to air in the combustible mixture entering the cylinder of an internal combustion engine.

Fuel cock: A valve used to control gas supply.

Fuel pressure: The pressure of the fuel entering the carburetor.

Gasket: A preformed material used between flat surfaces to effect better sealing.

Generator: A unit driven by an accessory drive to provide a supply of electricity for use in the airplane.

Ground test: The act of checking the performance of the engine on the ground prior to flight.

High pitch (propeller): The maximum positive working angle of propeller blades relative to the plane of rotation.

High tension booster coil: An electrical device used to supply high tension current to the spark plug at starting. The original energy for the coil comes from a battery.

Hydraulic clutch: A clutch which receives its engaging motion from a liquid under pressure.

Idle speed: The lowest speed at which an engine can operate smoothly.

Exhaust gas: The produucts of combustion which are discharged from a cylinder.

Exhaust gas analyzer: An instrument which indicated by analysis of exhaust gases the fuel-air ratio of the mixture supplied to an engine.

Exhaust pipe (stack): The pipe through which the exhaust is discharged, used either separately or as part of the manifold.

Idler gear: A gear used to transmit force from one gear to another.

Ignition: The firing of an explosive mixture of gases, vapors, or other substances by means of an electric spark.

Ignition cable: The insulated wires which are enclosed in the ignition harness and which conduct electricity from the magneto to the spark plugs.

Ignition harness: The assembly of conduits, manifold, and ignition cable, used to conduct electricity from the magneto to the spark plugs.

Impeller: The rotating member of a centrifugal pump or blower, which imparts energy to the fluid.

Induction system: The system in an engine through which the incoming air and fuel-air mixture are inducted into the cylinder.

Inertia starter: A starter incorporating a flywheel the speed of which is increased until sufficient momentum is obtained to turn an engine through several revolutions, at which time a clutch is engaged.

Intake port: The opening in a cylinder by which the fuel-air mixture enters the combustion chamber.

Intake valve: The valve in the cylinder which permits the fuel-air mixture to enter the combustion chamber at definite intervals.

Low pitch (propeller): The minimum positive working angle of propeller blades relative to plane of rotation.

Magneto automatic spark advance: A magneto designed to regulate spark timing automatically in accordance with engine rpm or power output to obtain maximum engine efficiency.

Manifold pressure M.A.P.: The pressure in the distribution chamber usually measured in inches mercury absolute.

Mixture control: An auxiliary control fitted to a carburetor to allow a variation of fuel-air mixture strength.

Multiplate clutch: A clutch consisting of a number of friction plates and disks.

Nacelle: An airplane structure, not part of the fuselage, generally housing the engine installation for purposes of streamlining.

Normal rated horsepower: The maximum permissible horsepower output which may be used for continuous operation.

Octane rating (antiknock value): The whole number nearest to the percentage by volume of iso-octane in a blend of iso-octane and normal heptane that the fuel matches in knock characteristics when compared by a prescribed method of test.

Oil cooler: A small air-cooled radiator for cooling the lubricant after its return from the engine and before the delivery to the oil tank.

Oil dilution: The method of temporarily lowering the viscosity of engine lubricating oil for cold weather starting by injecting fuel into the oil system.

Oil pressure relief valve: A spring-loaded valve in the delivery side of a forced lubrication system provided to maintain a constant discharge pressure by bypassing part of the oil to the pump inlet.

Oil seal: The means of preventing the entrance or escape of oil from one chamber to another or to the outside.

Overspeed: A speed greater than the maximum permissible for take-off.

Petcock: A small cock, faucet, or valve set in a system to control the flow of a fluid.

Pinion: A gear with a small number of teeth designed to mesh with a rack or a gear with a large number of teeth.

Piston displacement: The mass of fluid displaced by the piston when it travels from the bottom of its stroke to the top of its stroke; the product of the piston stroke and cylinder bore area.

Planetary: A system of gears all of which are either driving or being driven by the same gear, rotating around a common axis.

Preiginition: Ignition of the charge in a cylinder which takes place before the spark occurs frequently resulting from a hot spot.

Pre-oiling: The act of filling the lubricating passages in an engine with oil prior to starting the engine.

Pressure altitude: Altitude based on pressure alone.

Priming (fuel): The operation of injecting fuel into a cylinder or induction system to assist starting.

Priming (pump): The operation of filling a pump intake with liquid to expel the air.

Propeller blade: An arm of a screw propeller.

Propeller governor: A device for regulating the speed of an aircraft engine by changing the propeller blade angles.

Radial engine: An engine having the cylinders arranged radially around the crankcase.

Reduction gearing: A gear system which effects a lower speed of the driven element relative to the speed of the driving element.

Revolutions per minute, R.P.M.: The number of times each minute the crankshaft revolves around its axis.

Scavenge: 1. To remove burned gases from the cylinder.
2. To remove oil from the engine sump.

Skirt (piston): The bearing surface of a piston, consisting of the plain cylindrical portion between the ring immediately above the piston pin boss and the bottom ring.

Sludge: Material formed by the decomposition of the lubricating oil and the products of combustion. It is partially soluble in lubricating oil and is carried around in suspension in the oil. Eventually some of this material deposits on engine parts in the form of soft or hard lacquer-like deposits.

Solenoid: A hollow electrical coil used to produce a magnetic field.

Starter: A mechanism used to turn an engine over generally for starting.

Stroke (piston): The distance a piston moves from top center to bottom center.

Supercharger: A compressor used to supply air or combustible mixture to an engine at a pressure greater than atmospheric.

Table of Limits: A list of recommended clearances used during the assembly of engine parts.

Tachometer: An instrument for indicating the revolutions per minute of a revolving shaft.

Take-off: To leave the surface of the land or water; to begin flight.

Take-off horsepower: The maximum permissible horsepower output, not to be used for more than five minutes duration, used for take-off or during emergency operation.

Test club: A specially designed four bladed fan with blades of fixed pitch calibrated for engine test purposes.

Thermocouple: A combination of two dissimilar metals having a common junction and used to determine the temperature at any specific point through the measurement of the thermoelectric current generated by the unit.

Thermostat: An automatic device for regulating temperature.

Throttle: A valve incorporated in or just outside the carburetor controlling the volume of air and vaporized fuel delivered to the engine.

Top center: The piston position at the beginning of the power or intake strokes.

Torque wrench: A calibrated tool for measuring the amount of torque applied when tightening a part.

Trunnion: A projection on a ring or carrier, used for supporting small gears or pinions, usually having a bearing surface.

Vacuum pump: A pump designed to produce pressure less than atmospheric pressure.

Valve clearance: The clearance between the valve stem tip and rocker arm roller when the valve is closed.

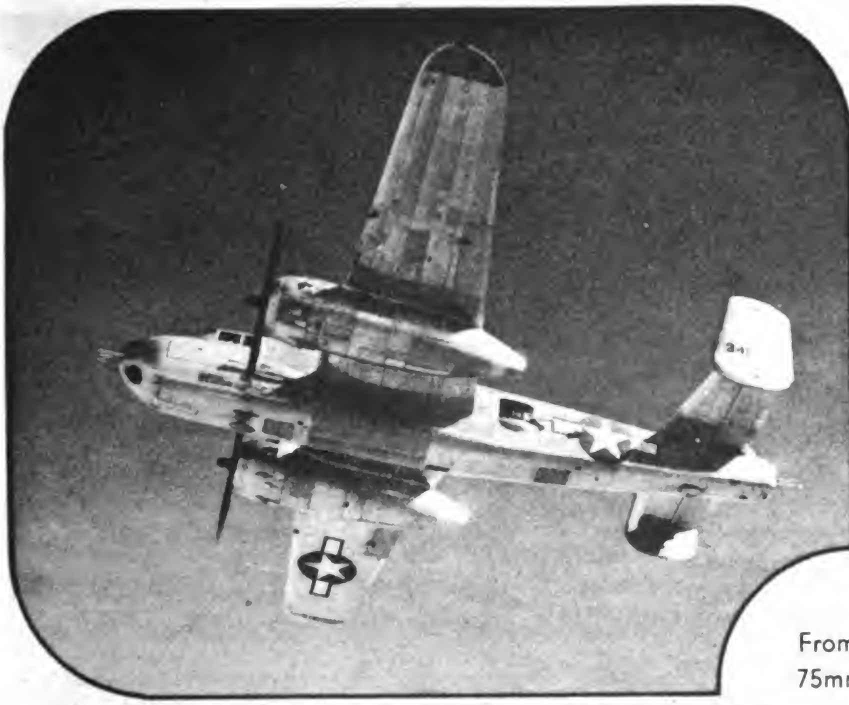
Side view shows characteristic rounded tail.

Curtiss four-bladed Electric propeller is a feature.

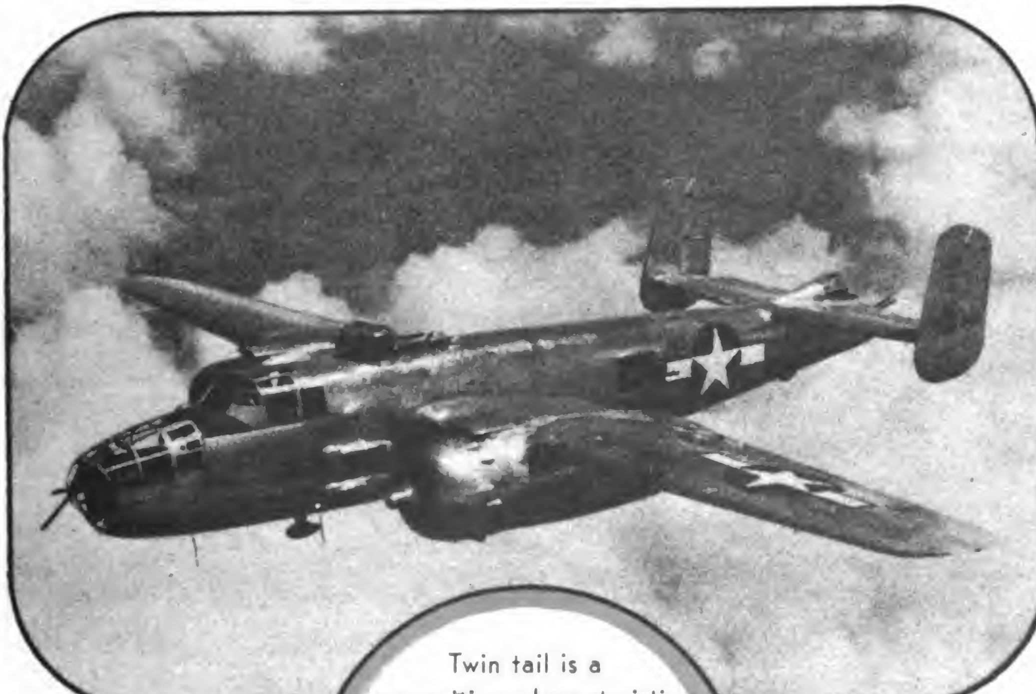
Wings folded, **Helldiver** is compact on carriers.

CURTISS HELLDIVER

Navy's SB2C, is representative of the hardest-hitting among all U. S. warplanes. Described by the Navy as its "Sunday punch", the Helldiver is equipped with a Curtiss electric propeller and powered by a Wright Cyclone 14. With its clean aerodynamic design and powerful engine, the big SB2C is husky enough to carry a potent load of bombs, yet fast enough to keep up with a fighter escort.



From below; notice
75mm cannon in nose



Twin tail is a
recognition characteristic

NORTH AMERICAN B-25 MITCHELL

Army Air Forces' medium bomber, has fought in every war theater, helped pave way for every major offensive. Powered by two Cyclone 14's, the B-25 in its latest version is armed with a 75mm. cannon and four .50 caliber machine guns in the nose, plus four other fixed guns firing forward, two waist guns, two tail guns, and two upper turret guns, making it the most heavily armed plane of its size.

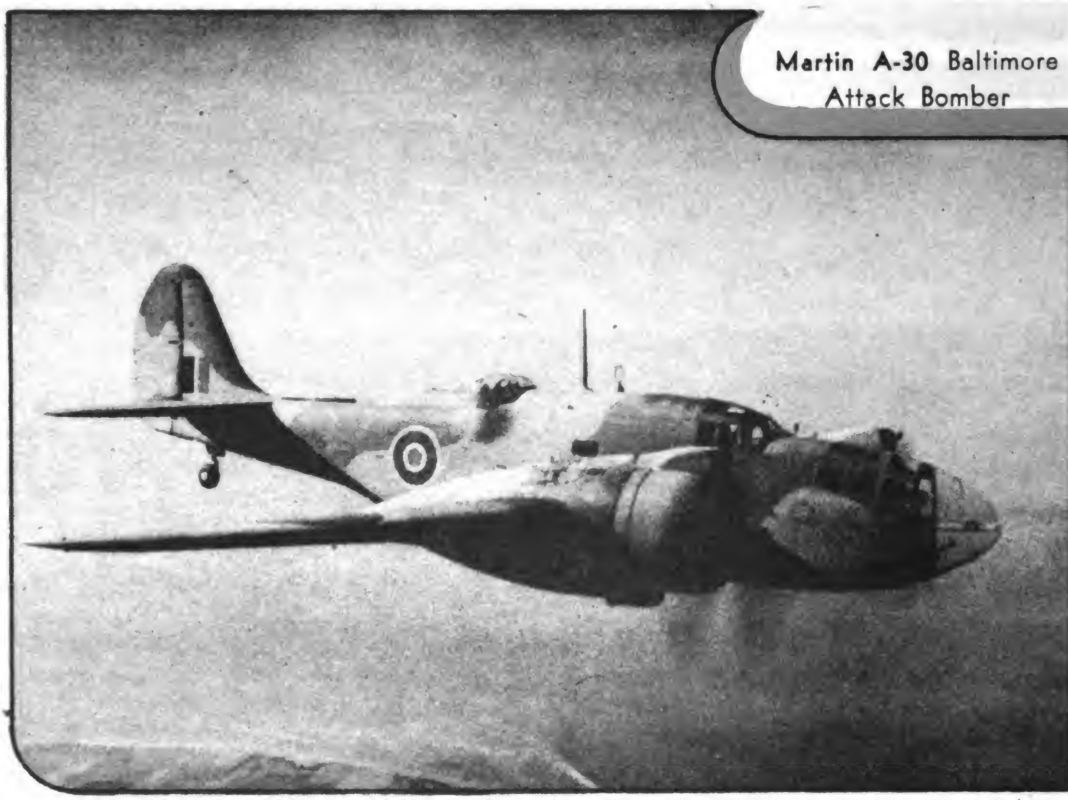
Above, **B17G** in flight; below a closeup

BOEING B-17 FLYING FORTRESS

Until the Boeing B-29 the heaviest bomber, the B-17 has served as workhorse of large-scale bombing of Nazi Germany throughout the war. Powered by four Cyclone 9's, the B-17 in its latest models bristles from new ""chin turret" to tail gun with armoring. A highly "flyable" plane, the Fort has made Air Force legends; returning to base on one out of four engines, recovering from a 10,000-foot dive, surviving shellfire again and again.

LOCKHEED C-69 CONSTELLATION

Designed as a "super" luxury airliner for TWA before the war, arrived in time to serve as giant express transport for military use. Powered by four Cyclone 18's of 2,200 horsepower each, the shark-shaped plane flew across the country in six hours and 58 minutes.



Martin A-30 Baltimore Attack Bomber

North American BT-9, Basic Trainer

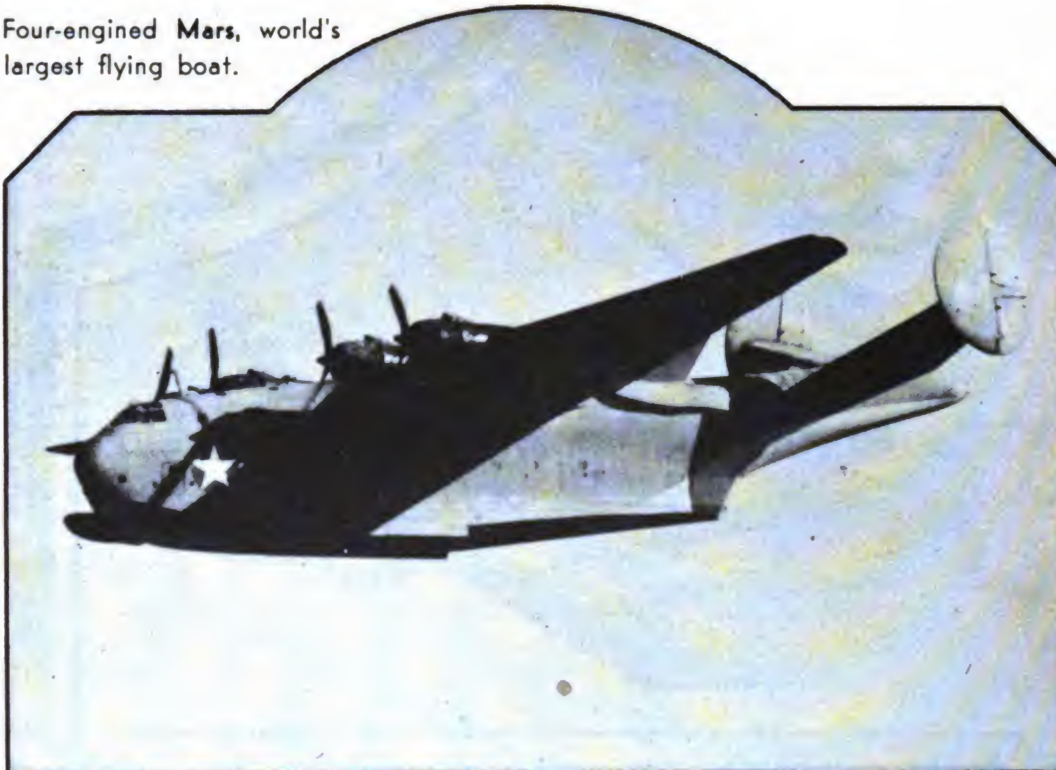
Grumman Wildcat,
Navy Fighter

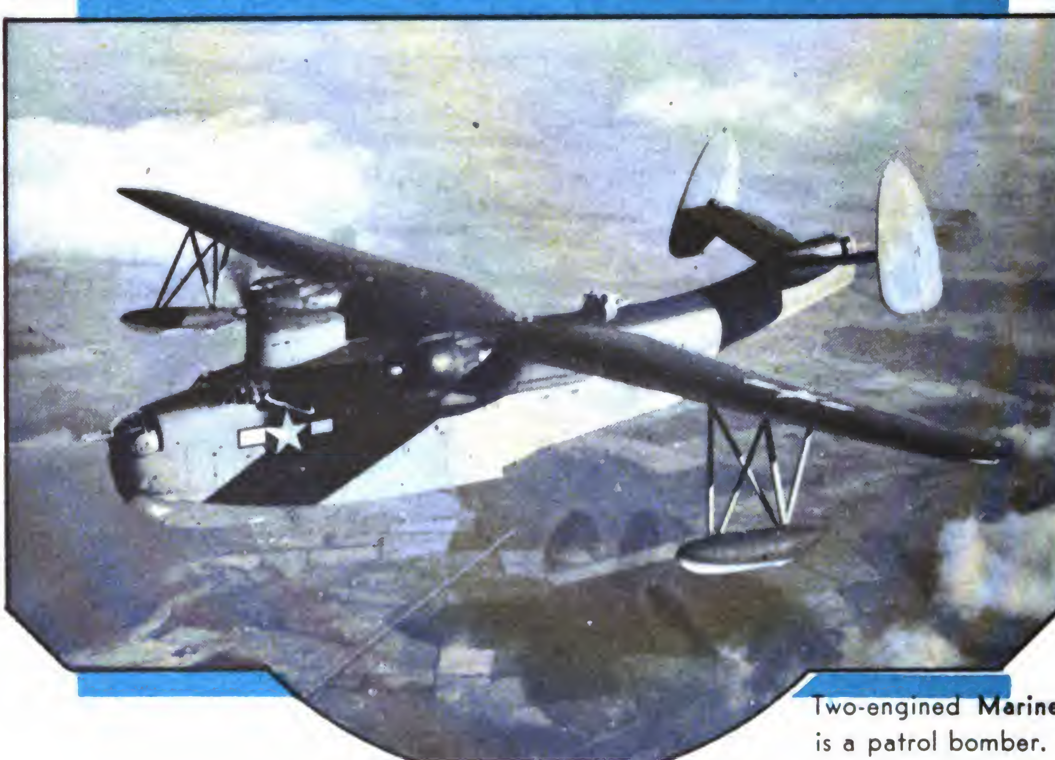
Grumman Avenger,
Navy Torpedo Bomber

THE GRUMMAN FAMILY

With their stubby fuselages and squarish wings, Grumman Navy planes became familiar sights in every theater of action in World War II. Here are two of the family: the Grumman Wildcat, and the Grumman Avenger. Avenger, powered by a 1700 horsepower Cyclone 14, can carry a 2,000-pound marine torpedo in fully enclosed compartment.

Four-engined **Mars,** world's largest flying boat.





Two-engined **Mariner** is a patrol bomber.

MARTIN MARS, MARTIN MARINER

Represent two of the most advanced types in heavy-duty, long range flying boats. Mars, world's largest flying boat, is powered by four Cyclone 18's of 2,200 horsepower each. Mariner, tough, hard-hitting patrol bomber, is powered by two Cyclone 14's. Both aircraft have proven Martin's advanced ideas in seaplane design, helped Martin plan for coming flying boats of even greater potentialities.

Douglas A-20 Havoc

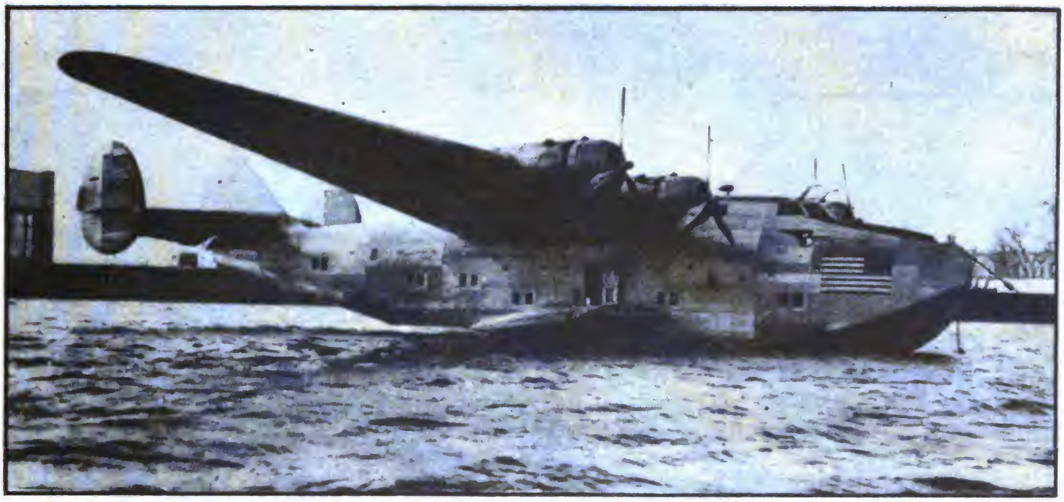
Douglas SBD Dauntless

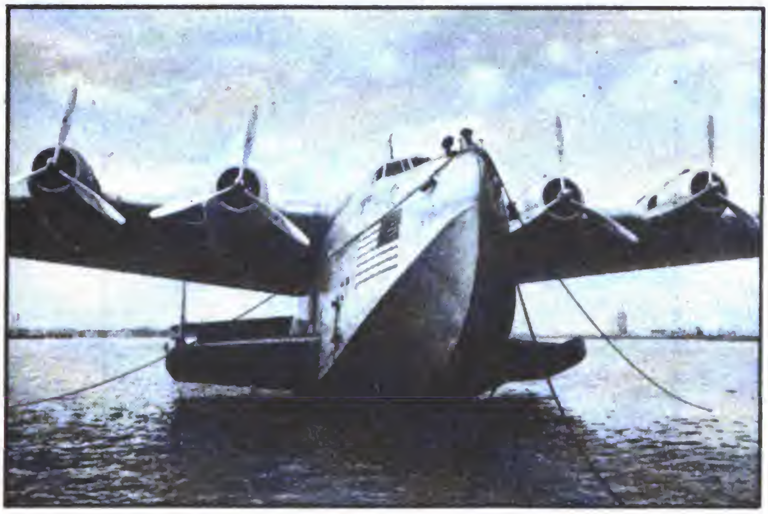
CURTISS COMMANDO

Largest twin-engined transport, Curtiss Commando (bottom photo) is an example of a heavy-duty, long-range plane tried and proven by war and immediately convertible to the uses of peace. Planned originally as a commercial transport, the Commando appeared in time to be used for swift ATC Army transport use as the C46. Powered by two Cyclone 18's of 2,200 horsepower each driving Curtiss electric propellers, the CW-20 version will carry 36 passengers and record loads.

BOEING B-29 SUPERFORTRESS

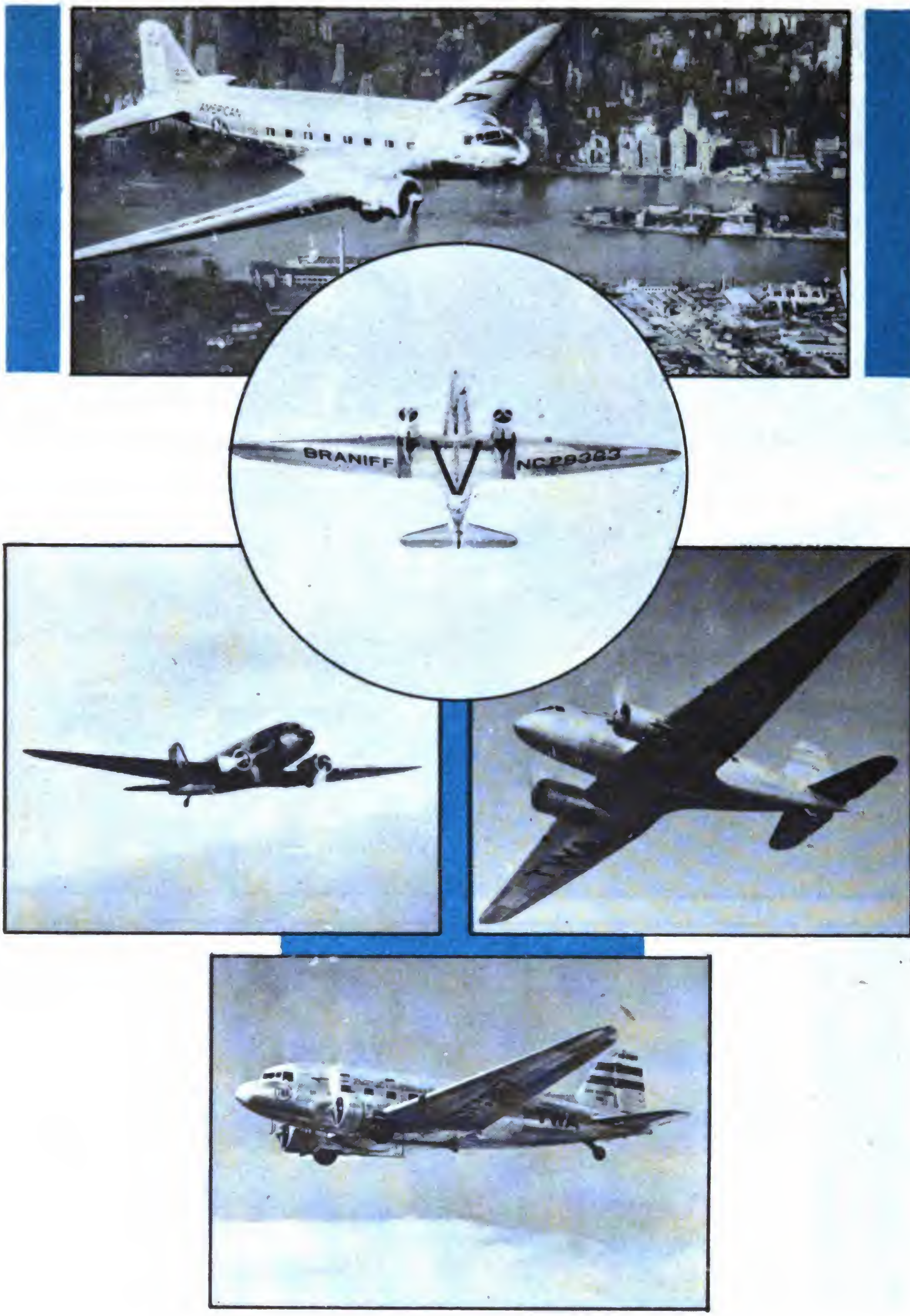
Heaviest, fastest, longest-ranged bomber, was developed for high-altitude, long-distance bombardment. First announced raid, upon Japanese territory, was made in 1944; subsequent raids have pummelled Japanese industries on the Japanese mainland. Powered by four Cyclone 18's of 2,200 horsepower each, the B-29 is heavily armed, fast as a fighter, equipped with pressurized cabins fore and aft.





BOEING 314 CLIPPER

Four-engined flying boat used by Pan American Airways in its pioneering of regular-schedule ocean crossings, is powered by four Cyclone 14's. Capable of carrying as many as 74 passengers on short hops, the big plane flies up to 30 passengers on its ocean-crossing runs. Pan American in 1944 completed its 5,000th ocean crossing since inauguration of this service; most of these crossings were made in Clippers.

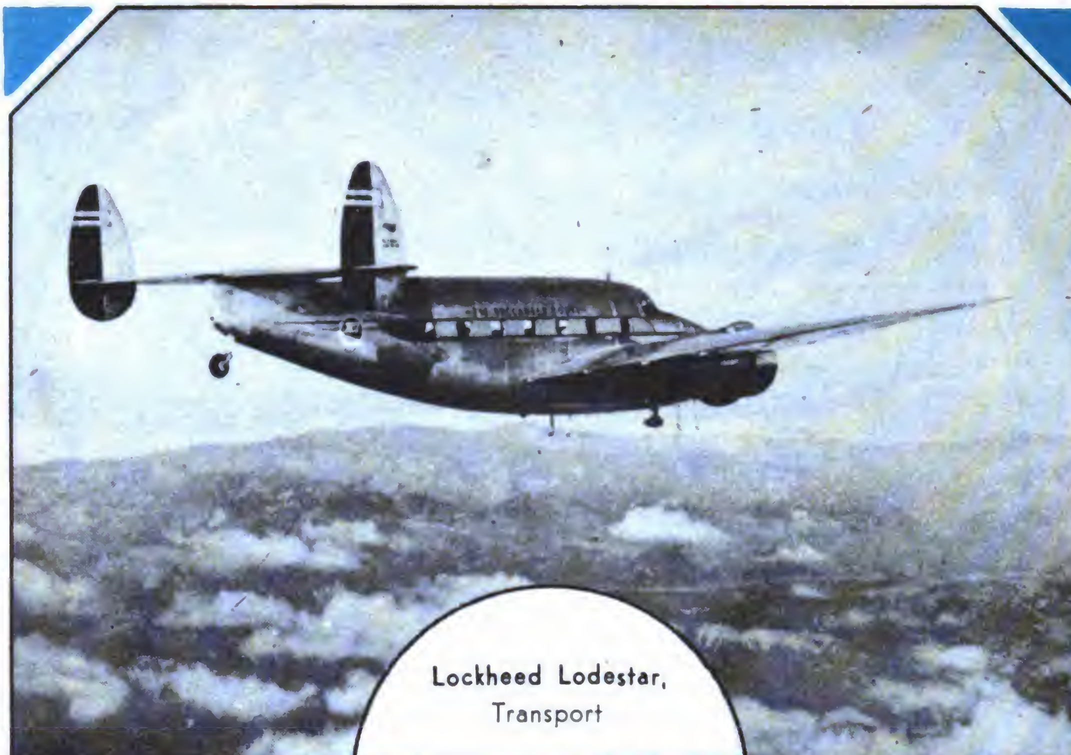


DOUGLAS DC3 AIRLINER

Is the successor to the 14-passenger DC2. The 21-passenger DC3 appeared in the middle thirties, became so successful that it was accepted not only by most domestic airlines, but was purchased in quantity for use abroad. Powered by two Cyclone 9's — either of which alone can sustain the craft in flight — the DC3 provides maximum comfort and hot meals for its passengers. DC3's shown here are operated by TWA, Eastern Air Lines, Braniff, and American Air Lines.

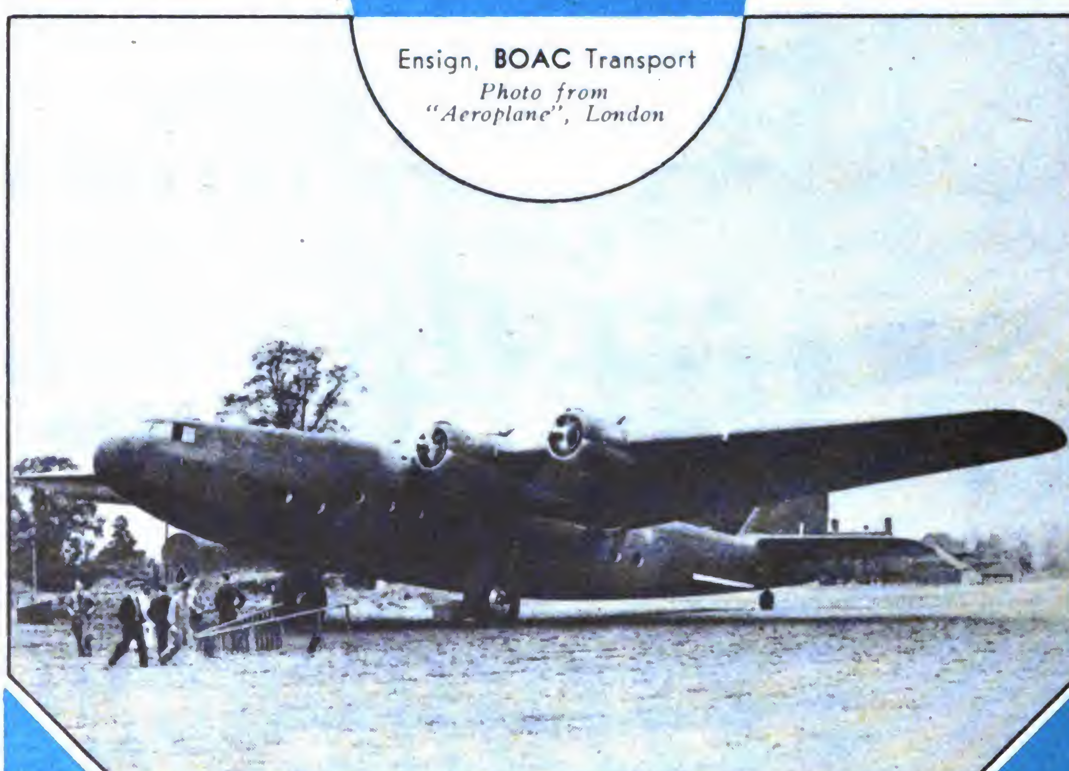
BOEING 307

33-passenger luxury airliner built especially for high altitude, long range flying, is powered, like the Boeing Flying Fortress, by four Cyclone 9's. Built along Flying Fortress lines and profiting from experience with that most successful of all bombers, the big transport has a pressurized cabin, weighs 21 tons, and has a wingspread of 107 feet. Bottom photo: TWA Stratoliner; Above: Pan American Stratoclipper.



Lockheed Lodestar,
Transport

Ensign, **BOAC** Transport
Photo from "Aeroplane", London



TWO VERSUS FOUR

Examples of good performance in two-engined transport and four-engined are these two planes, one American and the other British — both Cyclone-powered. At top is the Lockheed Lodestar, specifically one of the transports of National Airlines. Commercial counterpart of the famous Lockheed Hudson bomber, the Lodestar has served all over the world in both war and peace. Ensign, four-engined craft, is used by British Overseas Airways, manufactured by Sir W. G. Armstrong Whitworth Aircraft, Ltd.

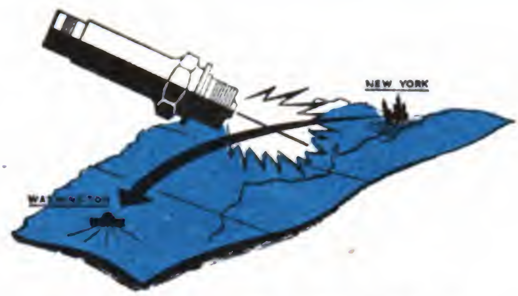
M-4 Tank
(Whirlwind Powered)

M-7 Gun Carrier
(Whirlwind Powered)

M-3, M-4, AND M-7

Army mobile equipment, provided not only a potent group of weapons, but also proved the efficiency and endurance of aircraft-type engines in earthbound vehicles. The husky R-975 Whirlwind, descendant of the J-5 which powered the planes of Lindbergh and Byrd was mounted in the tanks and gun carrier (M-7) in a special installation which employed a cooling fan to move air among the engine's cylinders. Signal Corps photos.

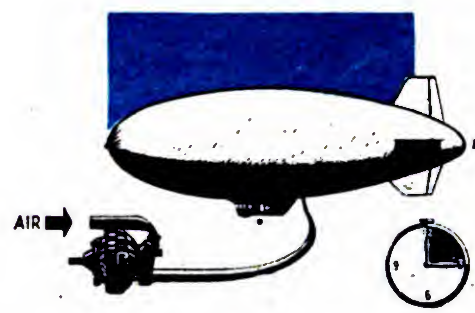
Fabulous Facts about the Cyclone



On a flight from New York to Washington, the spark plugs in a single Cyclone cylinder flash more than 81,000 times.

The four Cyclone 18's in a B-29 have more power than 88 average automobiles.

Equal in power to a fair-sized freight locomotive, 2,000 horse-power Cyclone weighs no more than the locomotive's wheels alone, takes up less space than there is in the cab.



In less than three hours, a Cyclone 18 requires for combustion more air than could be contained in a K-type blimp. The K blimps are each a block long and more than four stories high.

A Cyclone 18's oil-pumping system is capable of circulating at the rate of more than 43 gallons a minute (both for engine and by-pass).

Built into the compact cylinders of a Cyclone 14 is a cooling area of some 580 square feet — or more than the area of a pair of bowling alleys.

Enginology — Contents

The Result

More than twenty-five years of building aircraft engine power, matching increasing dependability of power plant with increasing efficiency of aircraft and ever-expanding knowledge of aerial navigation: this is the background for today's aviation.

The map of global air routes above is one concrete result. The map tells a story. It proves that continents and peoples are no longer separated by mountains and oceans, jungles and glaciers. The journey from Fairbanks, Alaska, to Petropavlovsk is a smooth ride above the clouds—about as long and as sure of accomplishment as the ride from New York to Los Angeles.

By flying over obstructions, instead of crawling around them, powered aviation cuts off miles. It also cuts time. Today no spot on earth is more than sixty hours' flying from the most remote destination. Tomorrow, powered flight will move starting point and destination even closer together.

(map by courtesy of "The Lamp", published by Standard Oil Co. (N.J.))

TWENTY FIFTH ANNIVERSARY

★ ★

WRIGHT AERONAUTICAL CORPORATION

WRIGHT

AIRCRAFT ENGINES